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TECHNICAL REPORT NO. 3-763

AN ANALYTICAL MODEL FOR PREDICTING
CROSS-COUNTRY VEHICLE PERFORMANCE
APPENDIX A: INSTRUMENTATION OF TEST VEHICLES

by

J. O. Egan

M. Keown



July 1967

Sponsored by

Advanced Research Projects Agency

and

Directorate of Research and Development

U. S. Army Materiel Command

Service Agency

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

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TECHNICAL REPORT NO. 3-783

**AN ANALYTICAL MODEL FOR PREDICTING
CROSS-COUNTRY VEHICLE PERFORMANCE
APPENDIX A: INSTRUMENTATION OF TEST VEHICLES**

by

B. O. Benn

M. Keown



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Project No. I-V-0-2500I-A-13I

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FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data which can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Research and Development, AMC, under Department of the Army Project 1-V-O-25001-A-131, Military Evaluation of Geographic Areas. The study was performed during the period June 1964 to November 1965 under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendices are:

- A. Instrumentation of Test Vehicles
- B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation)
- C. Vehicle Performance in Vertical Obstacles (Surface Geometry)
- D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry)

- E. Quantification of the Screening Effects of Vegetation on Driver's Vision and Vehicle Speed
- F. Soil-Vehicle Relations (Surface Composition)
- G. Application of Analytical Model to United States and Thailand Terrains

The study was conducted by personnel of the Area Evaluation Branch, Mobility and Environmental (M&E) Division, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief of the M&E Division; Mr. S. J. Knight, Assistant Chief, M&E Division; Mr. A. A. Rula, Chief, MERS Branch; Mr. Warren E. Grabau, Chief, Area Evaluation Branch; Mr. Jack Stoll, Chief, Field Test Section; Mr. Bob O. Benn, Acting Chief, Overseas Section; and Mr. Malcolm Keown, physicist, Overseas Section. Mr. Stoll directed the field test program. Messrs. Benn and Keown prepared this report.

The instrumentation support for this project was under the general supervision of Mr. C. B. Patterson, Chief, Technical Services Division; Mr. E. H. Woodman, Chief, Instrumentation Branch; and Mr. L. M. Duke, Chief, Measurements and Testing Section. Instrumentation project engineer responsible for equipment design and application was Mr. E. T. Estes. Messrs. W. L. Reynolds and B. C. Palmertree were instrumentation technicians.

Directors of the WES during the testing program and preparation of this report were COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	25.4	millimeters
feet	30.48	centimeters
pounds	0.45359237	kilograms
foot-pounds	0.138255	meter-kilograms
gallons per minute	0.06309	liters per second
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*
miles per hour	0.44704	meters per second

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9) (F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9) (F + 32) + 273.16$.

SUMMARY

An instrumentation system was developed to measure and record the dynamic responses of a moving vehicle to discrete environmental factors. Measurements of force to override vegetation, drive-line torque, vehicle linear and wheel or track rotational displacement, fuel consumption, acceleration, pitch, and hydrostatic pressure were made to determine the effects imposed on the vehicle by soil and longitudinal, lateral, and vertical obstacles.

The specific components of the system used for the various measurements are described and information concerning their positioning and operation is presented.

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY
VEHICLE PERFORMANCE

APPENDIX A: INSTRUMENTATION OF TEST VEHICLES

PART I: INTRODUCTION

Background

1. The main text of this report describes the development of an analytical model for predicting the cross-country performance of a vehicle. The model was based on an energy concept within the framework of classical mechanics that demanded that cause-and-effect relations be established between discrete environmental factors and vehicle response. The relations sought necessitated precise measurements of force required to override vegetation, drive-line torque, vehicle linear displacement, wheel or track rotational displacement, fuel consumption, horizontal and vertical acceleration, pitch, and hydrostatic pressure. To measure these factors simultaneously, extensive instrumentation was installed on each test vehicle.

Purpose and Scope of this Appendix

2. This appendix describes the instrumentation system used during tests in the United States and Thailand to measure the dynamic effects imposed on six moving vehicles by discrete environmental factors. The forces imposed by soil and longitudinal, lateral, and vertical obstacles were measured individually and in combination during water-land interface and cross-country tests reported in appendixes B, C, D, and F of this report.

3. The sensing elements (transducers), their locations on the vehicles, and the manner in which their respective signals were transcribed on the oscillograph records are described herein, and block diagrams of the power source requirements and signal paths are given. A summary of the manufacturer's specifications is given for each item in the system.

PART II: TEST VEHICLES AND INSTRUMENTATION SYSTEM

Vehicles and Transducers Used

4. The test vehicles were

<u>Main Tests</u>	<u>Supplemental Tests</u>
M29C amphibious cargo carrier (weasel)	M151 1/4-ton 4x4 utility truck (jeep)
M35A1 2 1/2-ton 6x6 cargo truck	M274 1/2-ton 4x4 light weapons carrier (mule)
M37 3/4-ton 4x4 cargo truck	
M113 armored personnel carrier (APC)	

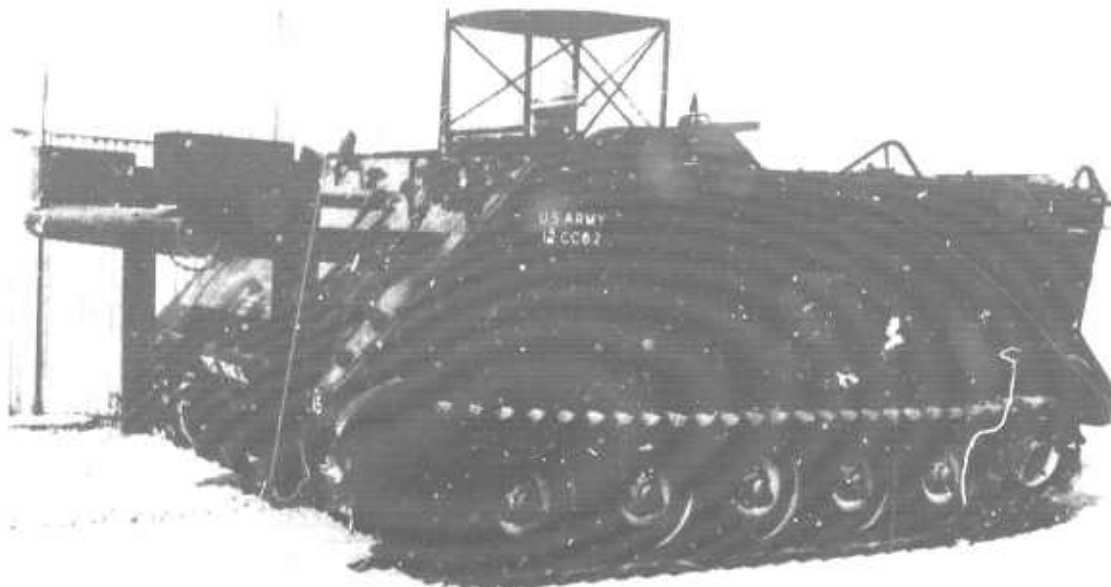
5. The components of the instrumentation system and their power sources are shown in block diagrams in plates A1 and A2. Plate A1 shows the power sources used to operate the transducers and recording instruments. In plate A2, the signal paths are traced from the transducers to the oscillograph. Table A1 lists the transducers used in the vehicles in this test program, and table A2 lists the transducers required for pertinent measurements according to test series. The manufacturers' specifications for each standard component used in the instrumentation system are given in table A3. The carrier amplifier, oscillograph, and console were mounted on a rigid, steel table specially designed to withstand shock, and this assembly was placed in the cargo area of the vehicles. Locations of the transducers in the vehicles used in the main tests and the approximate locations of those used in the supplemental tests are given in table A4.

Measurements Obtained and Equipment Used

Resistance of vegetation

6. To determine the resistance to motion offered by vegetation, the forces required for the vehicles to override various sizes of vegetation specimens were measured by load cells in a pushbar mounted in the front of the vehicle. Two versions of the pushbar were used, one on the M113 and one on the M37, as described in the following paragraphs.

7. Device used on M113. The pushbar and load cells designed and fabricated to be used with the M113 measured vertical and horizontal force components at vehicle speeds from 1 to 17 mph.* The bar, supported by a superstructure, was mounted horizontally at the front of the vehicle and was connected to the body by vertical and horizontal load cells (fig. A1).



4579-1

Fig. A1. Pushbar mounted on M113. The pushbar shown is an early model. In a later model the pushbar was extended farther from the vehicle to allow complete failure of a tree before it came in contact with the vehicle hull; thus, a more reliable computation of the total work (in foot-pounds) required to override the tree could be obtained.

A photograph of the later model is not available.

Two load cells (fig. A2), one parallel and one perpendicular to the longitudinal axis of the vehicle, were mounted near each end of the pushbar. The cells were calibrated using a standard load cell and proving ring. In addition to functioning as force transducers, the load cells served as structural members to provide stability about the vertical axis of the

* A table of factors for converting British units of measurement to metric units is presented on page ix.

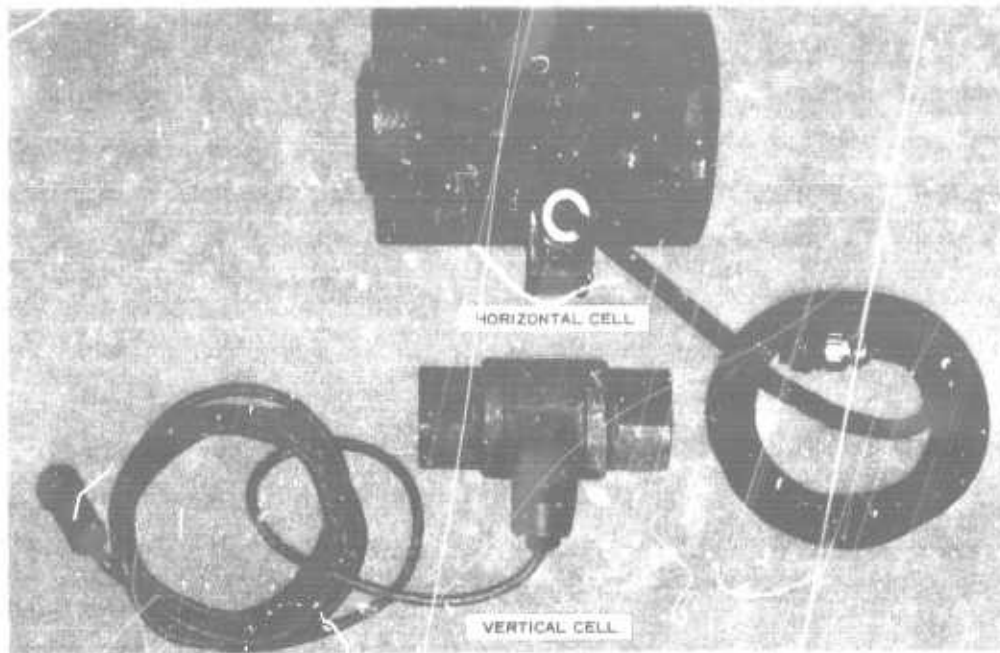


Fig. A2. Horizontal and vertical force transducers (load cells) used on pushbar mounted on M113



Fig. A3. Pushbar mounted on M37

pushbar. A horizontal stay rod was incorporated in the bar for stability against side thrust (not measured) applied by nonaxial loads. To minimize moments in the bar, a universal joint was coupled to the superstructure and the pushbar near one end of the bar. Design drawings of the entire system are shown in plate A3.

8. Device used on M37. The M37 pushbar and load cells (fig. A3) measured horizontal force only. The bar was suspended on hinges from a support fastened to the frame of the vehicle. This support provided lateral stability for the pushbar. Force on the load

cells (one at each end of the bar) was restricted to a single axis through the use of self-aligning bearings on the pushbar and loose-fitting eye-bolts at the other end of the load cells.

9. Record of measurements. The output signal for each horizontal load cell was transmitted by cable to a channel of the carrier amplifier (paragraph 29). After amplification, these signals were summed by a special circuit to provide a continuous record of the total horizontal force. Direct summation of the force magnitudes was possible since the two horizontal load cells responded to externally applied forces in parallel directions. Similar circuitry summed the input signals of the vertical force transducers and provided a record of the total of all vertical forces.

Torque

10. Devices used. A quantitative measurement of torque was needed to determine the total tractive force for each test. This measurement was obtained with a direct contact, slip-ring torque shaft mounted between the transmission and the last differential. The voltage input and output were carried by four ring-and-brush combinations (slip rings) to and from a Wheatstone bridge strain-gage arrangement (fig. A4). The output voltage of such a strain-gage bridge transducer is proportional to the applied torque. The carrier amplifier was used with the torque shaft to generate the voltage required to drive the galvanometer in the oscillograph.

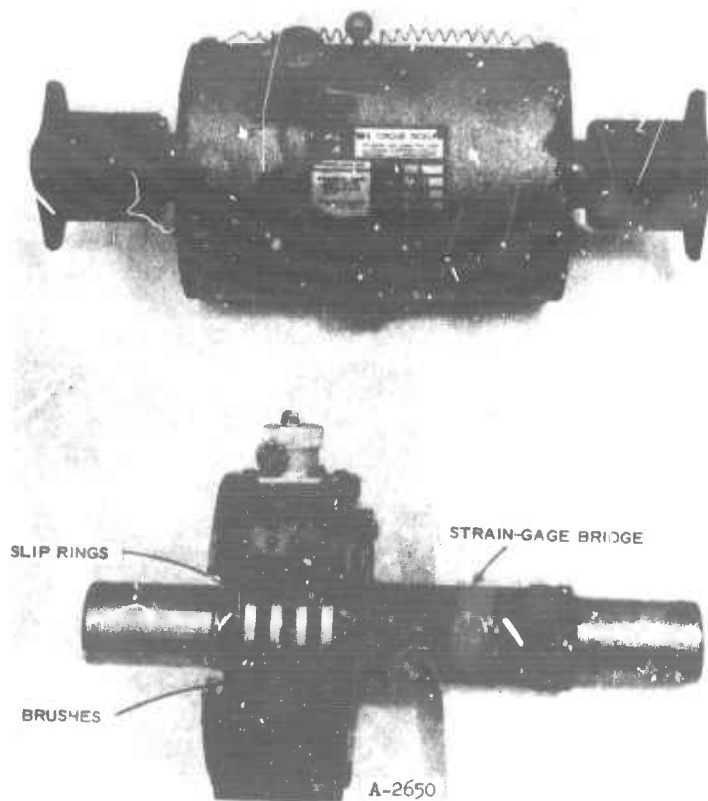
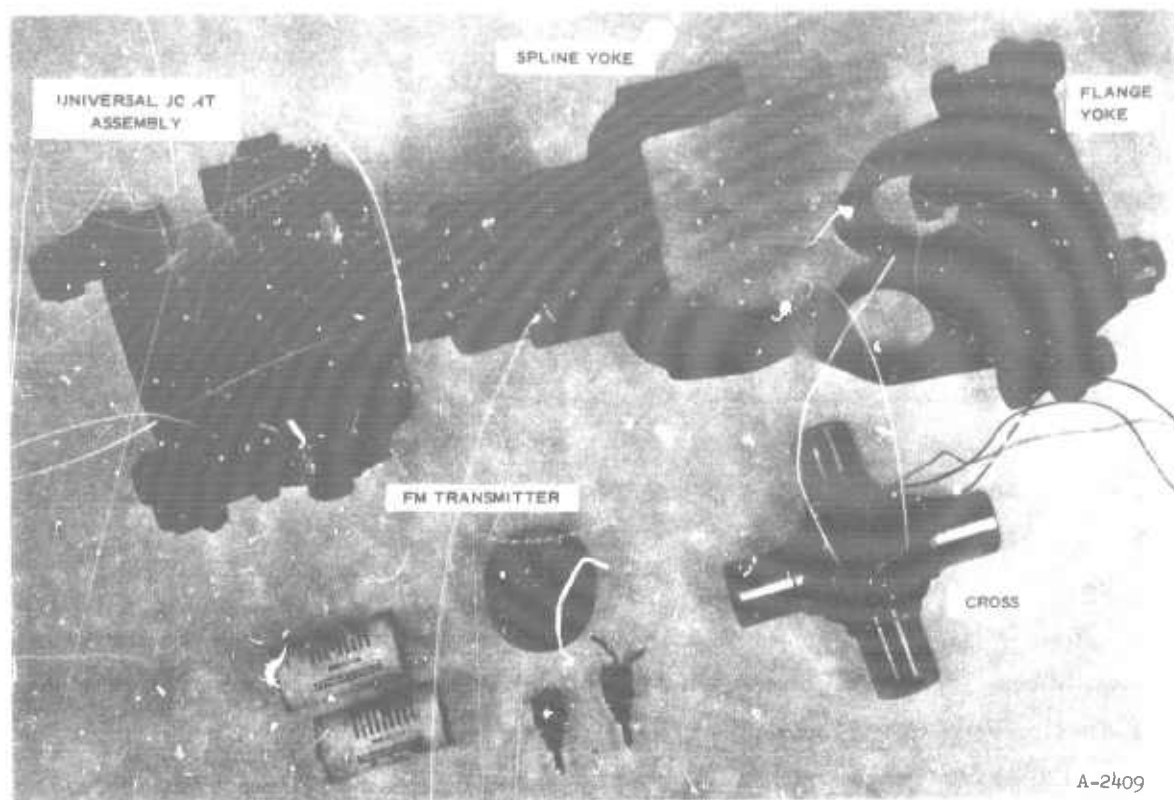
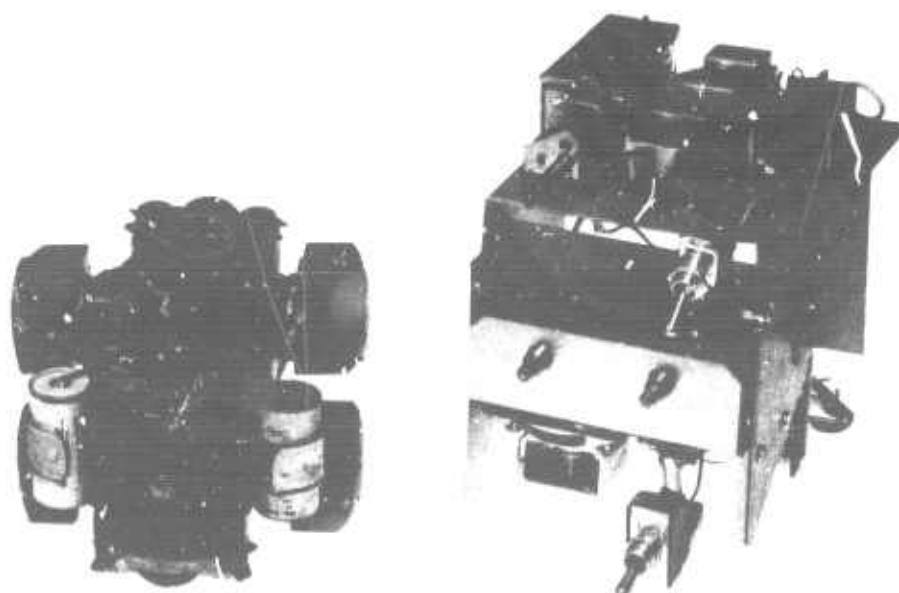


Fig. A4. Slip-ring torque shaft used on M29C



a. Unassembled



b. Assembled

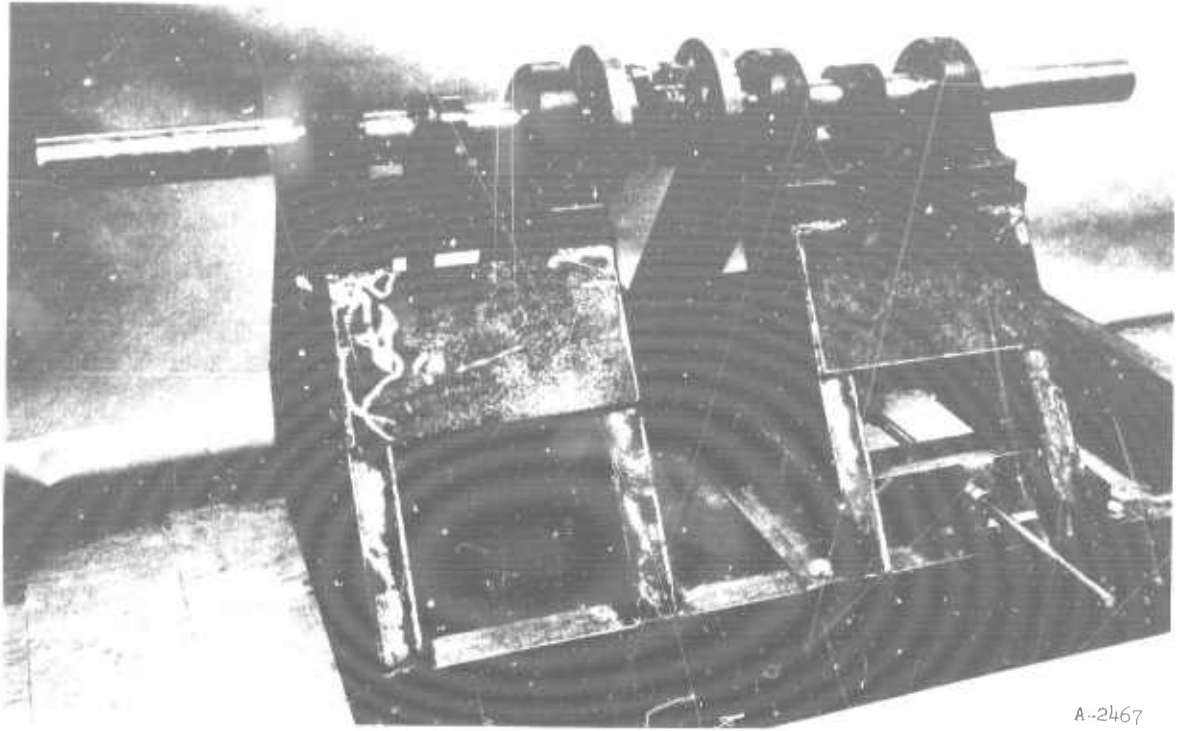
Fig. A5. Torque meter used on M113, M37, and M35A1

The torque shaft was used only on the M29C.

11. A standard torque shaft could not be used on the M113 because the space between the transmission and differential was not great enough to permit its installation; nor could it be used on the M37 and M35A1 trucks, because it would have reduced the ground clearance and thus affected vehicle performance in vertical obstacle tests. For these three vehicles, a torque meter was used that consisted of strain gages mounted on the universal joints and a short-range telemetry transmitter. Components of this system are shown in fig. A5. A change of torque produced a proportional change in transmitter frequency, which was transformed by the receiver into an output voltage which in turn caused a deflection of the oscillograph galvanometer.

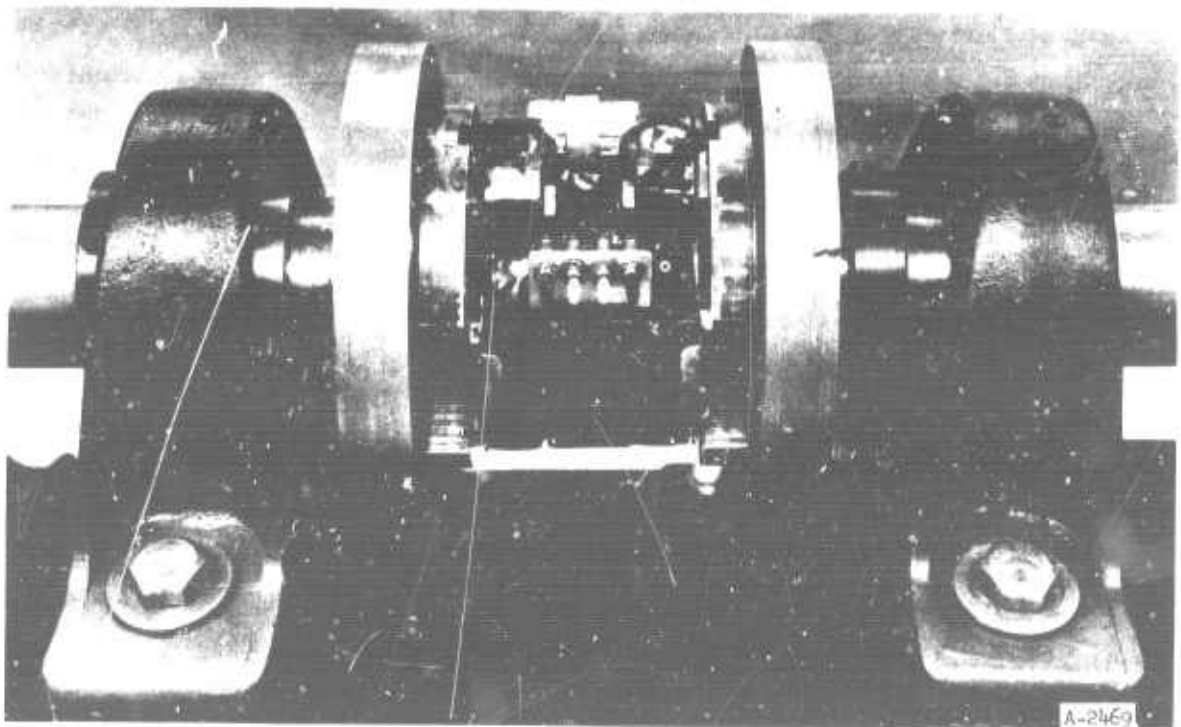
12. Calibration. The torque meter and torque shaft were calibrated using the apparatus shown in fig. A6. The torque meter or shaft was mounted between two shafts of the calibrator. One shaft was attached through a radius arm to a load cell secured to one side of the calibrator base; the other was connected to the opposite side of the base by a radius arm and a force-applying, threaded rod. In effect, this produced a static condition of two torques, equal in magnitude but opposite in direction; a torque value was obtained by interpreting the load cell reading. By adjusting the nut on the force-applying rod, various static torques could be applied, and a calibration curve was obtained for the torque measuring devices. The torque meter was heated to about 110 F to simulate field temperature before it was calibrated. A typical calibration curve is given in plate A4. A calibration reference of deflection in inches and torque output was established on the oscillogram before a test.

13. Since individual tests involved different torque maxima, three calibrating resistors were incorporated in the torque meter so that three ranges of torque magnitude could be recorded over the maximum range of approximately linear deflection. Three of the four switches on the control panel (fig. A7) were connected to these calibrating resistors, which could be switched across one of the legs of the strain-gage bridge transducer, thus causing the transmitter to emit a signal representing a known torque. The torque meter mounted in the M113 is illustrated in fig. A8.



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Fig. A6. Torque meter or shaft calibration apparatus



A-2469

Fig. A7. Torque meter mounted between the two shafts of torque calibration apparatus

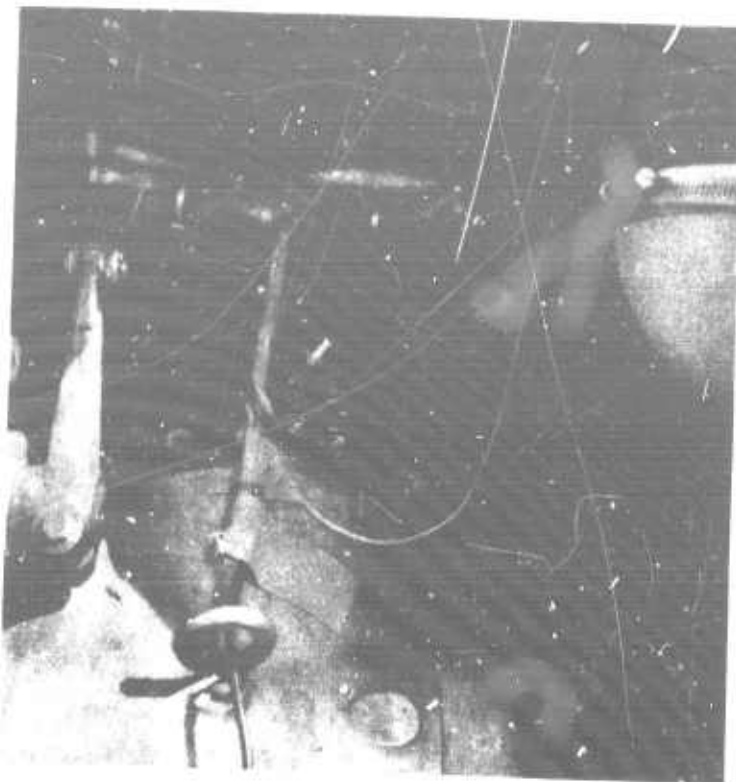


Fig. A8. Torque meter mounted in the M113

Linear displacement

14. Single factor tests. In single factor tests, where vehicles moved in as straight a line as possible, actual distance was measured using a fishing reel with a line that passed around a perforated idler wheel mounted between a light source and a photoelectric cell (fig. A9). Thus a discontinuity in a line trace was recorded on the oscillogram at the instant a perforation was in front of the light source. Since the circumference of the idler wheel was known, each discontinuity represented a given distance traveled. The distance-metering device mounted on the rear of the M113 is shown in fig. A10.

15. Cross-country tests. For cross-country tests, which involved changing directions to avoid lateral obstacles, the line payout system was impracticable, so a method was developed that used measurements of the number of wheel or track revolutions and a point-marker system. In some instances, the actual path of the vehicle was chained to ensure accuracy.

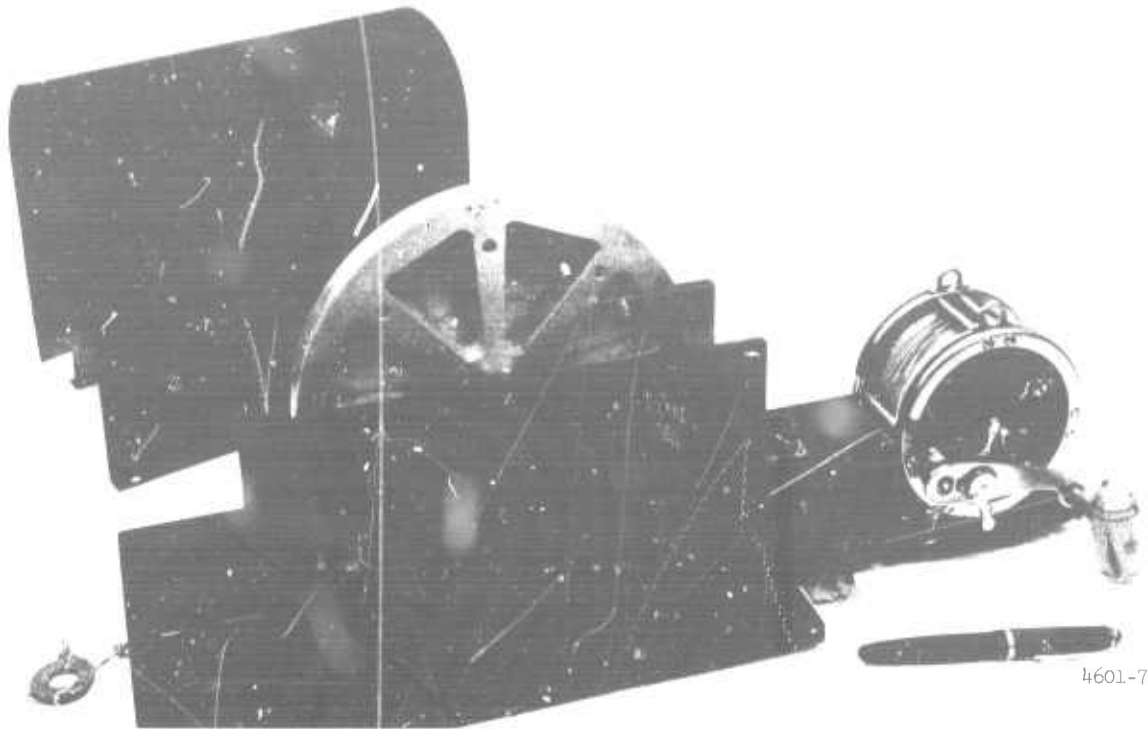


Fig. A9. Apparatus for measuring distance vehicle traveled

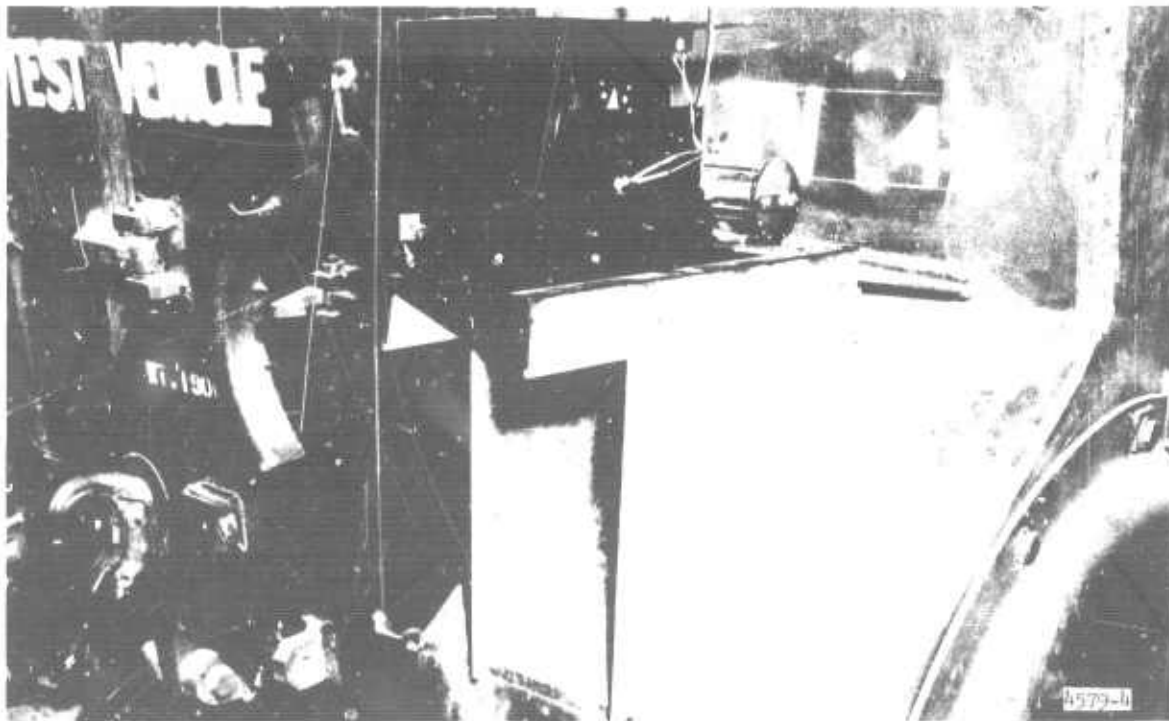


Fig. A10. Distance-measuring apparatus mounted on M113

16. To establish quantitative relations between specific terrain characteristics and vehicle performance parameters such as torque and speed, the position of the vehicle in relation to the actual course must be known. Where little or no slip was anticipated, wheel or track revolution counters were used to determine position (see next paragraph); where slip was probable, a ground position marker was used. The marker was a garden sprayer with a solenoid valve governed by a timer (fig. All).

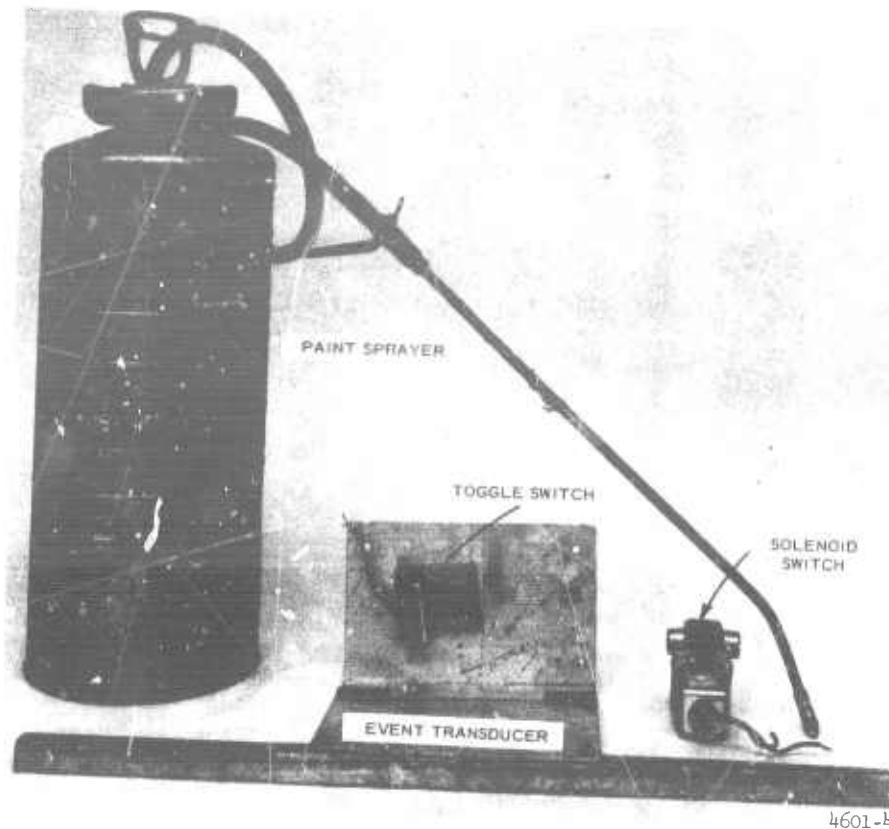


Fig. All. Ground position marker apparatus and event transducer

The valve opened at 5-sec intervals and ejected paint on the ground. A pip was recorded on the oscillogram at the instant the valve opened. Terrain position and oscillogram data then were related by matching the ground location of paint spots with corresponding pips on the oscillogram.

Rotational displacement

17. The number of revolutions completed by the drive shaft was counted, and the number of track or wheel revolutions was determined by multiplying the drive shaft revolutions by the proper gear ratios. Then,

with the circumference of the wheel or drive shaft known, the distance traveled by a point on the wheel or track could be computed. The revolutions of the drive shaft were counted by a magnet, mounted on the shaft (fig. A12), that passed near a dry reed switch mounted on the body of the

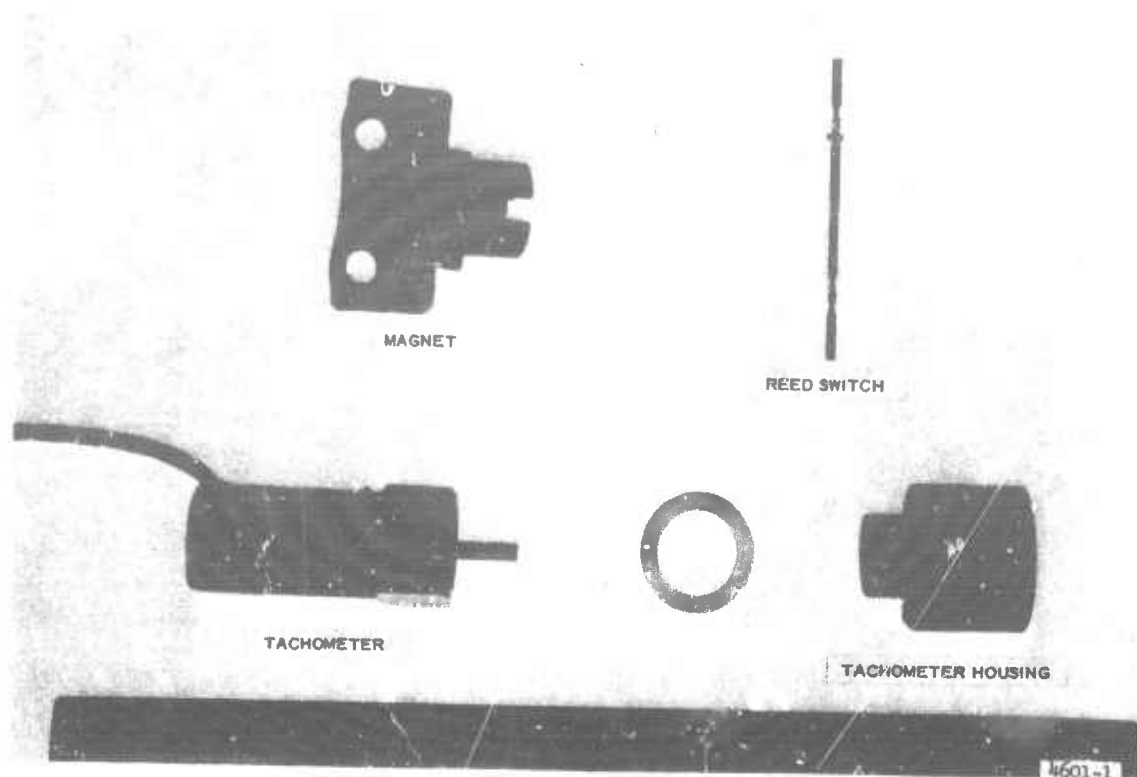


Fig. A12. Shaft revolution and speed (tachometer) transducers vehicle. Each time the magnet passed the switch, the circuit was completed, and a pip was produced on the oscillogram. The number of shaft revolutions was converted to rotational displacement. This method of determining rotational displacement was used on the M151, M37, M35A1, and M29C vehicles. The M113 does not have an exposed section of drive shaft, so shaft revolution counters were mounted on both left and right drive lines between the steering control differential and the drive sprockets.

18. Slip was determined by measuring the distance traveled by a point on the periphery of a wheel or track and comparing it with the actual linear displacement of the vehicle. Slip was computed as follows:

$$\frac{D_R - D_L}{D_R} \times 100 = \% \text{ slip}$$

where

D_R = rotational displacement of a point on the tractive elements

D_L = linear displacement of the vehicle

19. Rotational velocity of wheels or tracks, from which slip can also be calculated, was measured at the speedometer receptacle with a tachometer as a backup for the drive-shaft-revolution counter (paragraph 17). The tachometer is a direct-current generator whose output voltage is approximately linearly proportional to shaft rotational speed in revolutions per minute.

20. The tachometer trace was used only when the drive-shaft-revolution counter failed, since it was found to be in error at speeds below about 5 mph, and a substantial number of tests were conducted at speeds below that value.

Fuel consumption

21. Fuel flow was measured so that fuel consumption could be correlated with energy output of the vehicle. In the transducer used for this measurement (fig. A13), the force of the flow rotated a turbine connected to a small alternating current, pulse generator; the electromotive force (emf) pulse produced operated a digital counter (fig. A14). This counter transmitted a signal to the oscillograph after each 100 pulses from the flowmeter which was recorded as a pip on the oscillogram. The number of pulses (cycles) per second was determined by reading the lapsed time on the oscillograph between pips and dividing this into 100. The flowmeter was factory calibrated, and the amount of fuel flow per cycle was stated by the manufacturer. For example, calibration data for the M113 are given in plate A5.

22. The standard fuel pumps installed on the M37 and M113 vehicles did not maintain sufficient line pressure to ensure reliable operation of the fuel flowmeter, so electric pumps were installed; electric pumps are standard equipment on the M151. Bypass lines were installed on most vehicles so that fuel meters did not operate when the vehicles were moved

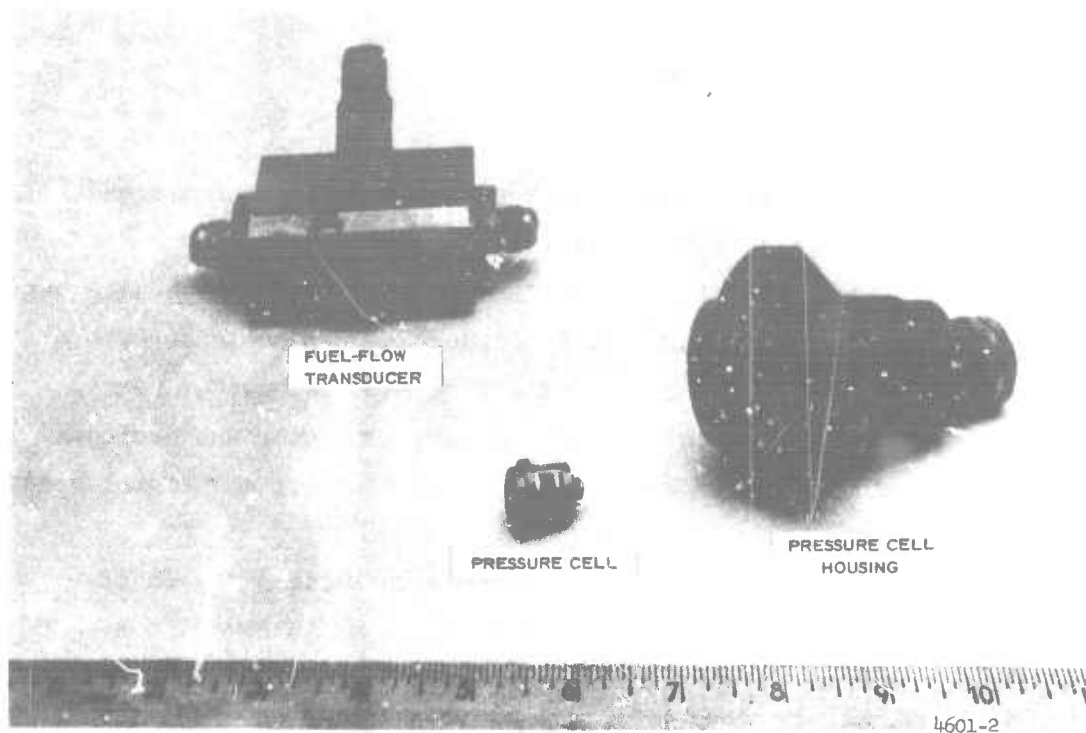


Fig. A13. Fuel flowmeter and pressure cell.

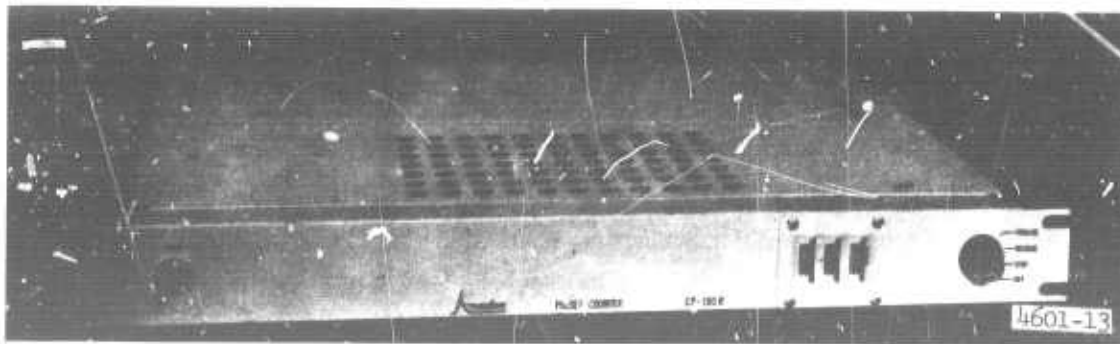


Fig. A14. Fuel-flow digital counter

from one test location to another. A fuel flowmeter could not be installed on the M35A1 because it interfered with the pressure control mechanism that maintained constant line pressure for the fuel injection system.

Acceleration

23. To obtain data on the lateral, longitudinal, and vertical components of acceleration to which the driver and cargo would be subjected as the vehicle encountered obstacles, two types of accelerometers

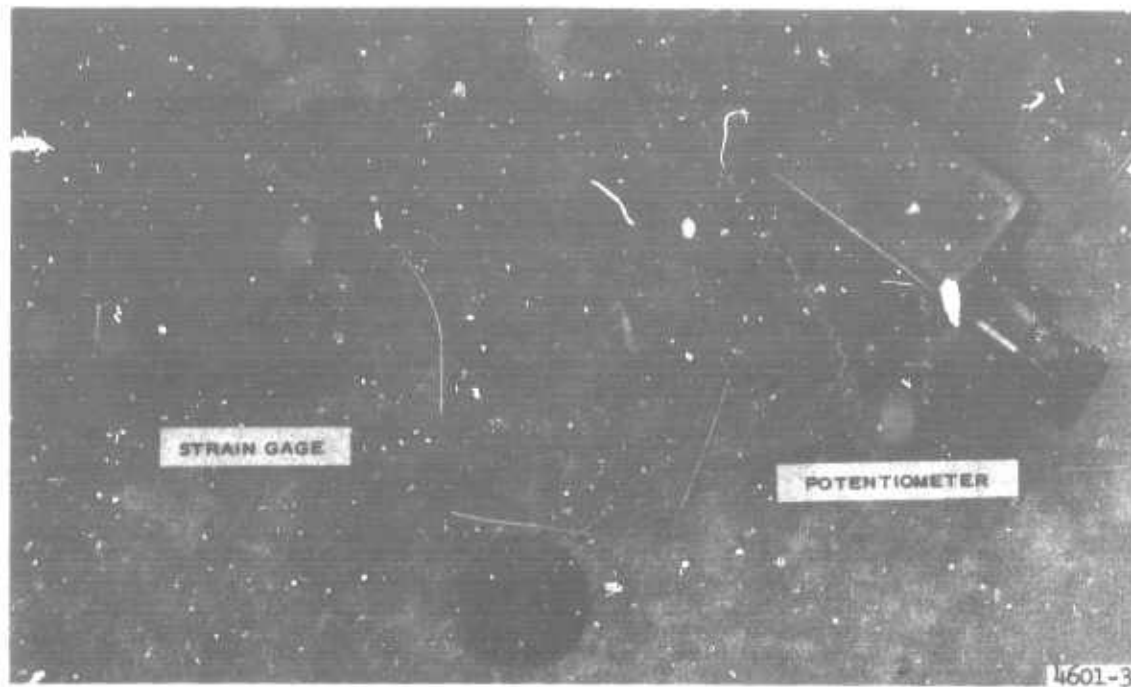
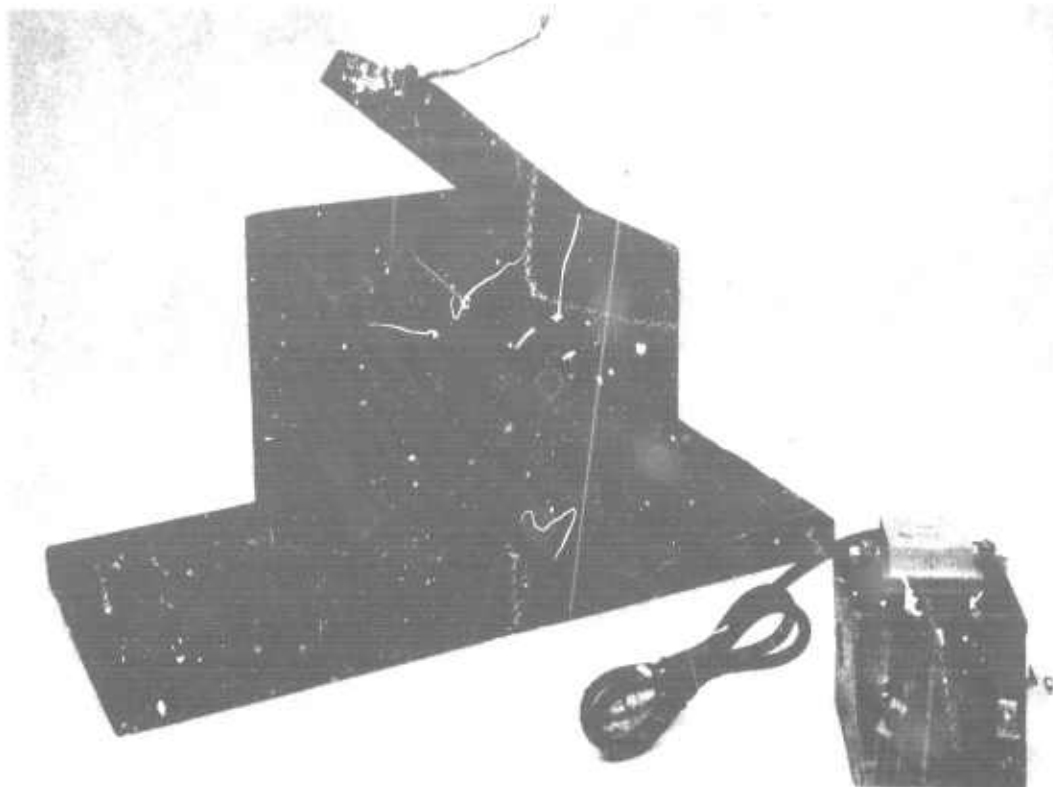


Fig. A15. Strain gage and potentiometer-type accelerometers

were considered, the potentiometer and the strain gage (fig. A15). After preliminary tests, the strain gage accelerometer was chosen as the more reliable under adverse field conditions. This transducer operates on the principle that certain materials experience a change in resistance proportional to applied strain. The strain is generated by an acceleration-sensitive mass which, in effect, causes the strain-gage bridge to be unbalanced and produce a voltage proportional to the acceleration.

24. Interference from unwanted high-frequency vibrations was reduced by mounting the accelerometer on a small steel cube (fig. A16) and resting this mass on damping foam plastic inside a rugged wooden mounting box (a mechanical low pass filter) which was then secured to the test vehicle.

25. The accelerometers were calibrated using the earth's gravitational field. When an object is subjected to a constant (or zero) velocity, the only force acting on it is gravity. Therefore, a motionless accelerometer, with its sensitive axis vertical, produces a voltage proportional to the acceleration of the earth's gravitational field (1 g); if the accelerometer is rotated through a 90-deg angle, so that its



4601-5

Fig. A16. Strain gage accelerometer

sensitive axis is horizontal, gravity has no effect because the accelerometer is perpendicular to the gravitational field, and the output voltage is proportional to 0 g.* If the accelerometer is rotated another 90 deg in the same direction, a voltage proportional to 1 g, but of opposite sign** is produced. The oscillogram traces produced are -1 g, 0 g, and +1 g. If the accelerometer is rotated through 2π radians, the output voltage will follow a sinusoidal path and there will be two nulls (0 g) and two peaks (+1 g). For field calibration, the voltage output was considered zero when the accelerometer's sensitive axis was vertical; when it was turned over (180-deg rotation of the sensitive axis with respect to the earth's gravitational field), the change in output was equivalent to a 2-g difference.

* This assumes that the initial voltage is taken when the output of the accelerometer is at a maximum (parallel to the field).

** With respect to the voltage at 0 g assumed to be zero.

Pitch (longitudinal attitude)

26. A vertical gyroscope (fig. A17) was attached to the M29C and

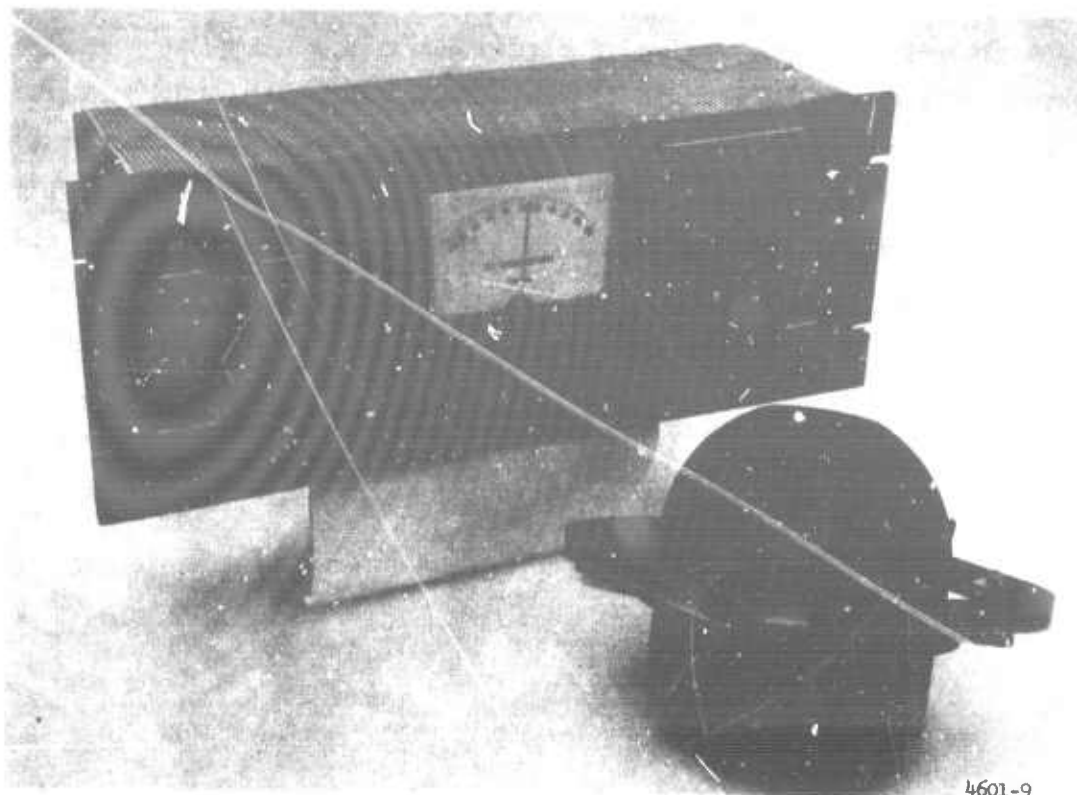


Fig. A17. Vertical gyroscope and control panel

the M113 to determine their pitch as they traversed vertical obstacles. This electrical device changes emf output as the test vehicle departs from the horizontal plane. The gyroscope was calibrated by rotating the vehicle through known angles, observing the change in voltage output, and establishing a voltage-angle relation, so that a given voltage correlated with a specific angle. For calibration in the field, various resistors were switched into the circuit, each producing a voltage representing a predetermined angle. Several deflection calibration steps were needed over the maximum linear range of deflection to provide flexibility for data recording.

Hydrostatic pressure

27. A precise relation between pitch angle and water depth is required to describe the transition of a vehicle from the floating to the

surface bearing mode. The position of the waterline determines the buoyancy forces and thus the effective weight and center of flotation of the vehicle, both of which appear to be significant factors. To measure the pitch angle-water depth relation, pressure cells (fig. A13) were mounted front and rear on the M29C and M113 vehicles for the water-land interface tests. These pressure cells were calibrated using a water manometer as a reference and obtaining calibration resistor equivalents as was done with the force transducers. The pressure cell mounted on the rear of the M113 is shown in fig. A18.

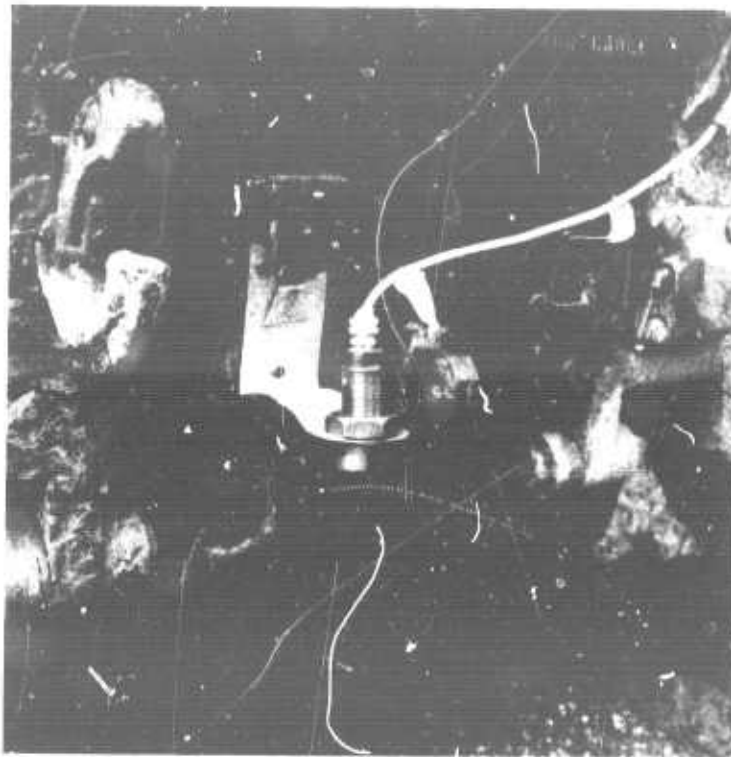


Fig. A18. Pressure cell mounted on M113

Event determination

28. Many of the quantitative data acquired were related to a particular event such as collision with an obstacle, change of direction, change in terrain type, etc. To identify the data with the event, one of the oscillograph channels recorded an event by a discontinuity on the trace. A circuit, consisting of an on-off switch, a battery, and a voltage divider to adjust input voltage to the oscillograph, was used. A

push-button switch was operated by the observer-passenger in the test vehicle each time a pertinent event occurred, and a toggle switch (fig. A11) was so mounted on the front of the vehicle that when the vehicle struck a marker on the test course, a circuit closed, causing a pip on the oscillogram. In addition, a telegraph key (fig. A19), fixed in parallel with

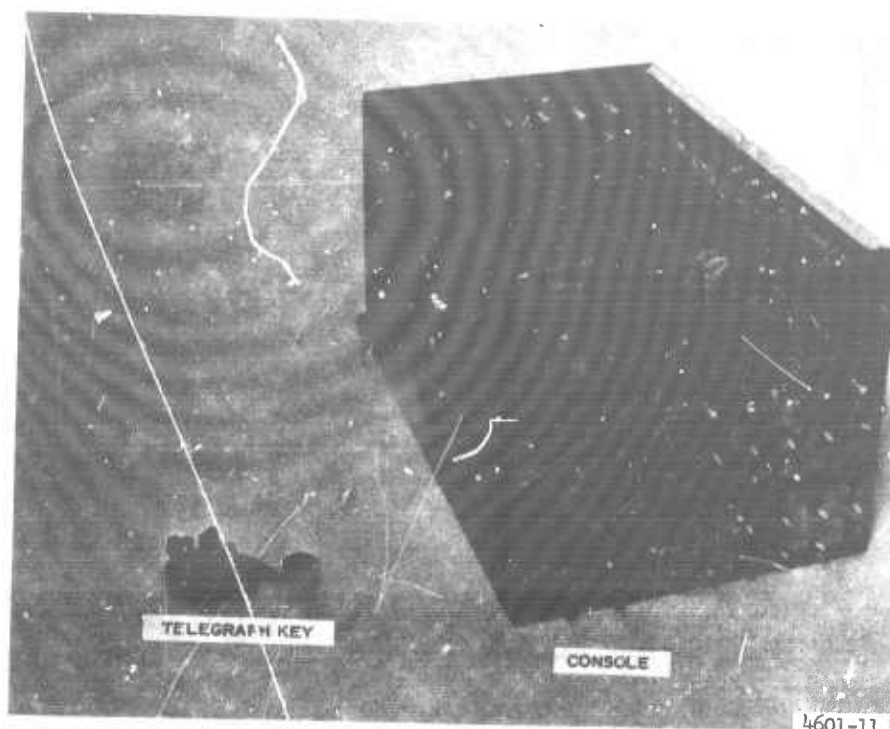


Fig. A19. Portable instrumentation console and telegraph key the two switches, was used to record the test number on the oscillogram prior to the start of each test.

Supplemental Equipment

Carrier amplifier

29. Several of the transducers used in the instrumentation system did not have sufficient output to drive the oscillograph galvanometers directly, so amplifiers were used (CEC Model 1-118, fig. A20). Because tests with the M37 and the M113 required amplification of eight information channels, two four-channel units were used with these vehicles. The M35A1 and the M29C required only four amplifier channels each.

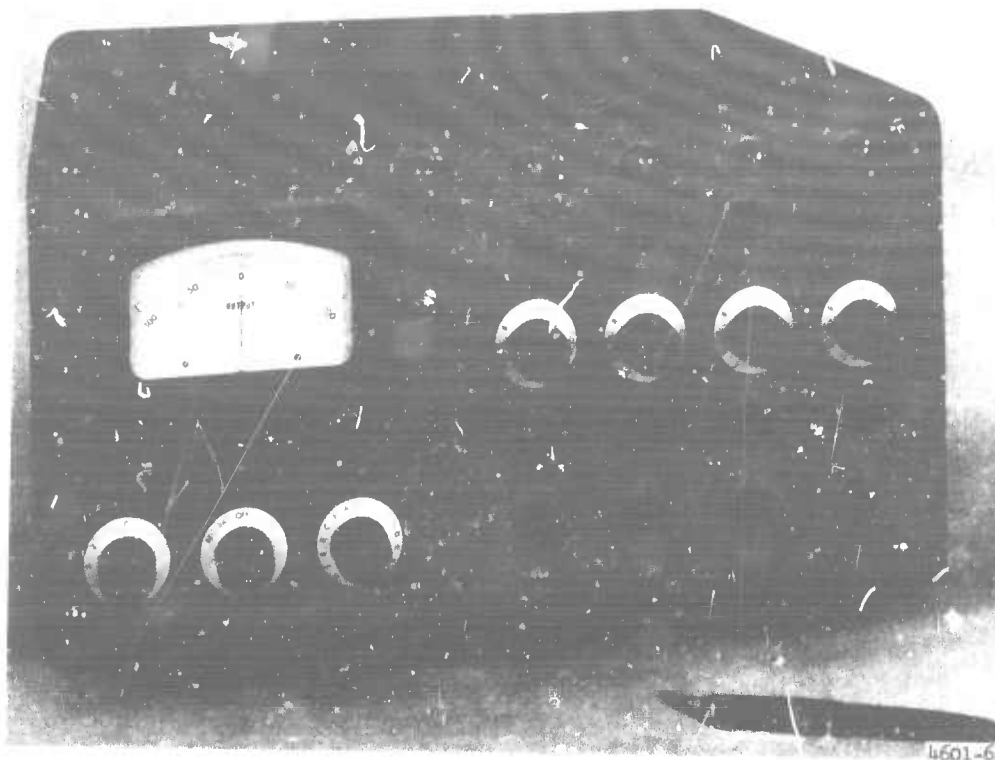


Fig. A20. CEC Model 1-118 carrier amplifier unit

30. Components of amplifier. The carrier amplifier unit has three basic components:

- a. The amplifier proper, which is a linear device designed to amplify the input signal to a magnitude capable of producing a satisfactory galvanometer deflection without significant distortion.
- b. A 3-kilohertz oscillator to excite the bridge circuits of the various strain gage transducers associated with the amplifier.
- c. The calibration unit which has a switchable precision resistance circuit that relates transducer output to galvanometer deflection, so that the deflection is a valid quantitative measurement of the physical factor in question.

31. Calibration unit. The calibration unit can switch various resistances in parallel with one of the legs of the bridge in the transducer, thus producing a resistance change that simulates an external mechanical factor. When switched in, each calibration resistor used with a given transducer gave an electrical equivalent to a fixed

mechanical factor. For example, a 10,000-lb force transducer may have calibration resistors equivalent to A = 535 lb, B = 1070 lb, C = 2140 lb, etc. These values are established when each transducer is calibrated through its associated cable to the amplifiers. The usual procedure is to switch in a selected calibration resistor and adjust amplifier gain for an easily read galvanometer deflection. The resistor is then switched out and a force applied to the transducer until the prior deflection is matched. This provides a relation between pounds of force and resistance; hence, any calibrating resistor can represent a known force for a particular transducer. By repeating this process at progressively higher force and resistance values, a series of calibration steps can be established for use in obtaining field measurements.

32. Record scaling. So that the records could be easily read, the maximum value of the quantity to be measured was estimated for each test and the proper scale set on the recorder. For example, the maximum horizontal force required to override a tree was estimated from the tree's diameter. The force calibration step most closely approximating the estimated force was selected and this calibration resistor was switched into the circuit to give a galvanometer deflection equivalent to a known force. A maximum linear deflection range of 4 in. was used to record the calibration step and subsequent force measurement. Deflection was adjusted to the desired amplitude by regulating the amplifier gain and attenuation controls.

Console

33. The complexity of the system required construction of a unit that incorporated the various control circuits and necessary mounting positions for equipment. This console, shown in fig. A19, contained an FM receiver (part of the telemetry system), a timer (associated with the ground position marker), various power control switches, and several calibration and attenuation circuits for the transducers that did not require a carrier amplifier.

Oscillograph

34. The transducer signals were recorded with a light beam oscillograph (fig. A21) which produced a galvanometer deflection proportional to

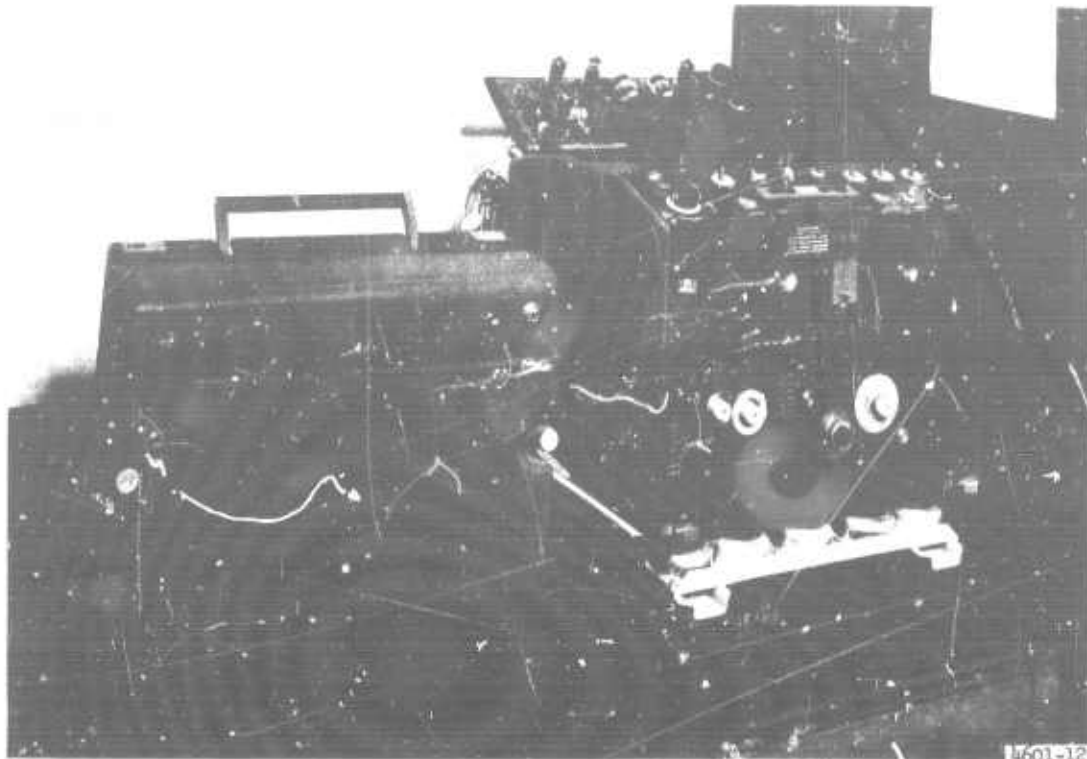


Fig. A21. CEC Model 5-119 recording oscillograph

each electrical signal; this, in turn, produced a visible trace on recording paper. The oscillograph (CEC Model 5-119) can print up to 36 traces on 12-in.-wide paper. An oscillogram obtained from a water-land interface test is shown in plate A6.

35. In the early part of the test program, a small (4-in.-wide, 12-channel), direct-print oscillograph and a portable 14-channel magnetic tape recorder were used. These were inadequate in field tests because:

- a. The tape recorder failed to record under peak shock conditions.
- b. Tape data provided no advantage for data reduction and analysis.
- c. The data recording process could not be directly observed without complex monitoring equipment.

36. The 36-channel oscillograph successfully resolved these problems and the direct-print process was readily adaptable to this model. The final instrumentation system included provisions for tape recording in the event that magnetic tape should be an asset in future tests.

37. A time trace, controlled by a timer in the oscillograph, related various events and quantities measured by the common independent variable, time.

PART III: CONCLUSION AND RECOMMENDATION

Conclusion

38. The systems described herein measured and recorded the desired responses with adequate reliability from the standpoint of the quality of data required. At times, difficulties were encountered in continuous operation of the relatively complex instrumentation systems because of the harsh environment (vibration, humidity, etc.) to which the equipment was exposed. Nevertheless, the dependability of the systems was considered good.

Recommendation

39. In the future, the adaptability of instrumentation and recording systems to automatic data reduction should be explored before final selection of these systems is made.

Table A1

Instrumentation Transducers Used in Tests

Transducer	Vehicle					
	M37	M35A1	M29C	M113	M151	M274
Torque:						
Shaft Meter	-- X	-- X	X --	-- X	-- --	-- --
Load cells (pushbar):						
Horizontal	X	--	--	X	--	--
Vertical	--	--	--	X	--	--
Driver's seat accelerometers:						
Lateral	X	X	--	--	--	--
Longitudinal	X	X	--	--	--	--
Vertical	X	X	--	--	X*	--
Cargo area accelerometers:						
Lateral	--	--	X	X	--	--
Longitudinal	X	X	X	X	--	--
Vertical	X	X	X	X	--	--
Fuel flowmeter	X	--	X	X	X	--
Event switch	X	X	X	X	X	--
Tachometer	X	X	X	X	--	--
Pressure cell**	--	--	X	X	--	--
Vertical gyroscope	--	--	X	X	--	--
Ground position marker	X	X	X	X	X	X
Timer	X	X	X	X	X	X
Drive shaft revolution counter	X	X	X	--	X	--
Drive-sprocket revolution counter						
Left drive line	--	--	--	X	--	--
Right drive line	--	--	--	X	--	--
Distance	X	X	X	X	X	--

Note: X indicates measurements taken in a particular test series.

* Mounted near driver's seat.

** Front and rear.

Table A2

Transducers Used in Various Test Series

Transducers	Test Series																		
	Longitudinal Obstacle			Lateral Obstacle			Vertical Obstacle			Water-land Interface			Soil Vehicle			Cross Country			
	M13	M37	M29C	M13	M37	M29C	M13	M37	M29C	M13	M37	M29C	M13	M37	M29C	M13	M37	M29C	
Torque:																			
Shaft Meter	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Load cells (pushbar):																			
Horizontal Vertical	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Driver's seat accelerometers:																			
Lateral				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Longitudinal	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vertical	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cargo area accelerometers:																			
Lateral				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Longitudinal	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vertical	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fuel flowmeter																			
Event switch:	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tachometer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pressure cells																			
Vertical Gyroscope																			
Ground position marker				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Timer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Drive shaft revolution counter				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Drive-sprocket revolution counter:																			
Left drive line	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Right drive line	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Distance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: X indicates measurements taken in a particular test series.
 * Event mark was recorded when the event switch on front of vehicle contacted a wooden reference marker.

Table A3

Condensed Manufacturer's Specifications for
Instrumentation System Components

Component	Specification
Accelerometers	Statham A3-5-350. 11 v max, 350-ohm bridge, <u>+5 g's</u> max
Carrier amplifier unit	Consolidated Electroynamics Corp., model 1-118. 115 v AC at 50/60/400 cps. Features include 4 carrier amplifiers, 3-KHZ oscillator for transducer excitation (5 v rms), and various calibration and attenuation networks. Each of the amplifiers will produce an output of 5 ma into a 24-ohm load from an input of 1.875 mv from a 120-ohm source. The frequency response is a flat <u>+5%</u> from 0-600 cps, and the output current is linear with the input data voltage to within 3% of max output.
Distance transducer (cord payout)	Photoelectric cell, Clairex type CL604. Cord, Cortland Line Co. No. 24 Premier braided linen. Elongation under 50-lb load, 3%. Reel, Penn Fishing Tackle Mfg. Co., Penn Master Mariner No. 349, gear ratio 2-1/3 to 1.
Force transducers (load cells)	<u>Horizontal component</u> Baldwin-Lima-Hamilton Corp., type U-1 (10,000-lb cell for M37 and 20,000-lb cell for M113). <u>Specifications:</u> <u>Accuracy:</u> Calibration inaccuracy is not more than <u>+0.25%</u> of full range at any point from 0% to 100% of capacity at 70 F. <u>Overload characteristics:</u> 120% of rated load will cause no adverse effects. 150% of rated load may cause a slight zero shift but will not impair measuring qualities of the cell. Repeated overload will, however, shorten the life of the cell. <u>Impact loading:</u> Shock loads having peak values in excess of 120% of rated capacity can affect calibration. If there is doubt as to peak value, units of larger capacity should be chosen. <u>Electrical data:</u> Resistance across power input terminals at 70 F, 120 ohms <u>+0.2 ohm</u> , increasing approximately 1 ohm for 50 F temperature rise. Resistance across output terminals 70 F, (Continued)

Table A3 (Continued)

<u>Component</u>	<u>Specification</u>
Force transducers (load cells) (Continued)	<p><u>Electrical data (continued):</u> 117 ohms ± 1.0 ohm. <u>Recommended supply voltage:</u> 5 v, 8 v max, AC or DC.</p> <p><u>Seal:</u> The load-sensitive element is hermetically sealed and is unaffected by changing humidity.</p> <p><u>Temperature limit:</u> Max 150 F.</p> <p><u>Vertical component</u> Budd Co., type LUE-10K (used on M113)</p> <p><u>Accuracy:</u> Calibration inaccuracy is not more than $\pm 0.25\%$ of full range at any point from 0% to 100% of capacity at 75 F.</p> <p><u>Overload characteristics:</u> 120% of rated load, no effect; 150%, slight zero shift; 200%, zero shift and possible damage.</p> <p><u>Electrical data:</u> Output at rated load, -2.00 mv/v; input resistance, 350 ± 0.5 ohms; output resistance, matched to input resistance within 1 ohm; input voltage, 10 to 20 v recommended.</p> <p><u>Seal:</u> Hermetically sealed.</p> <p><u>Temperature:</u> Safe range, -40 to +150 F.</p>
Fuel flowmeter	Flow technology type, milliflow model FTM 1.5 lb Digital Counter, Anadex CP-100R
Generator (electric power supply)	Kohler model Output voltage: 115 v, 60 HZ Output power: 1.5 kw Fuel: gasoline
Ground position marker (pressure spray)	Control solenoid, Asco, 24 v, DC. Timer, specially constructed by WES. 5-sec trigger circuit.
Gyroscope	Electronic Specialty Co., vertical gyro, type N3200 Vertical accuracy: $\pm 1/2$ deg (average) Caging time: 1 min max Maximum acceleration: 30 g's in any direction Gimbal freedom: Roll ± 80 deg Pitch ± 60 deg Gyro motor: Requires 24 v, DC

(Continued)

(2 of 4 sheets)

Table A3 (Continued)

Component	Specification
Oscillograph	Consolidated Electrodynamics Corp., model 5-119. 115 v AC at 60 cps. This instrument can record any static or dynamic phenomenon which is convertible to an analog voltage; uses CEC-type 7-200 or 7-300 series galvanometers. Other features are 36 separate channels, examination of data as they are being recorded, <u>+2</u> -in. deflection, built-in timer.
Pressure cells	Consolidated Electrodynamics Corp., type 4-312, 5 psi max Pressure limit: 1.5 times rated pressure Temperature range: -320 F to +300 F Electrical excitation: 5 v AC/DC (10 v max) at a carrier frequency of 0-20 kc Input and output impedance: 350 ohms <u>+5%</u> at 77 F
Tachometer	Servo-tek Type Automotive. 7 v/1000 rpm; standard SAE tachometer fitting
Torque pickup	Baldwin-Lima-Hamilton Corp., Baldwin SR-4, type A, torque pickup (5000 in.-lb) <u>Specifications:</u> <u>Accuracy:</u> Nominal dynamic calibration accuracy is <u>+0.25%</u> of full scale with no temperature change, <u>+0.5%</u> of reading per 100 F temperature change. <u>Overload characteristics:</u> 120% of rated torque will cause no adverse effects. 150% of rated load may cause a slight zero shift, but will not impair measuring qualities of the shaft. 200% of rated torque will cause a zero shift and may damage the shaft. Max operating temperature is 140 F; max operating speed, 5000 rpm. <u>Electrical data:</u> Resistance across power input terminals at 70 F, 350 ohms +3 ohms. Resistance across output terminals at 70 F, 350 + 3 ohms. Recommended supply voltage 12 v, AC or DC.
Torque telemetry system	<u>Transmitter</u> Industrial Electronics Corp., model T62-A. This unit is designed to operate with a 120-ohm strain gage transducer bridge and to transmit a modulated (FM/FM) carrier. The subcarrier oscillator provides the bridge excitation and has a center frequency of

(Continued)

Table A3 (Concluded)

<u>Component</u>	<u>Specification</u>
Torque telemetry system (Continued)	1600 HZ. RF carrier frequency is tunable from 88 to 108 MHZ. The unit is potted for extreme environmental use. Two 4.5-v, Burgess-type H-233 mercury batteries are needed for power.

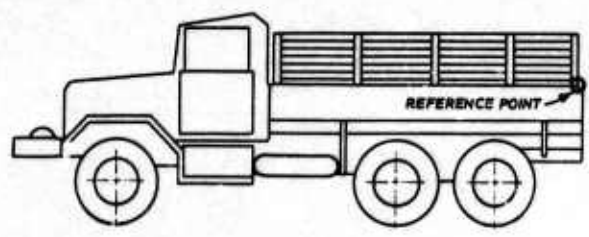
Receiver

Industrial Electronics Corp., model R64-A. This unit is designed for use with the above transmitter, and the RF and subcarrier frequencies are the same (1600 HZ +10%, SC) (88-108 MHZ, RF). The RF and subcarrier demodulators convert the received signal to an equivalent output voltage, and amplitude frequency and wave form of the transducer signal is reproduced.

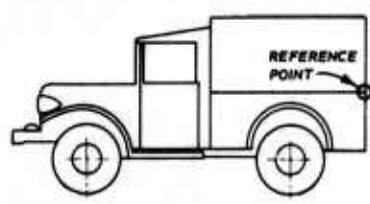
Note: HZ, hertz; KHZ, kilohertz; MHZ, megahertz; RF, radio frequency.
(4 of 4 sheets)

Transducer	M35A1 2-1/2-ton Cargo Truck				M37 3/4-ton Cargo Truck			
	Displacement from Reference Point* in ft			Location	Displacement from Reference Point* in ft			Location
	Longi- tudinal + Fore - Aft	Lateral + Star- board - Port	Vertical + Up - Down		Longi- tudinal + Fore - Aft	Lateral + Star- board - Port	Vertical + Up - Down	
Torque	14.7	4.1	-1.0	Between transmission and transfer case	8.7	2.8	-1.9	Between transmission and transfer case
Load cells (pushbar)	--	--	--	--	16.2	0.0	-2.4	Front of vehicle on axis
Drive shaft revolution counter	3.3	4.4	-1.8	Rear differential	8.3	2.8	-1.9	Rear universal joint transfer case and
Accelerometer at driver's seat	14.0	1.8	0.0	Under driver's seat	8.4	1.3	-1.8	Under driver's seat
Accelerometer in cargo area	7.5	1.3	0.0	Left rear cargo compartment wall	3.5	1.2	-1.9	Left rear wall of cargo compartment
Tachometer	11.7	4.4	-0.5	In speedometer receptacle at the rear of transfer case	7.0	3.5	-1.9	In speedometer receptacle at the rear of transfer case
Gyroscope	--	--	--	--	--	--	--	--
Event switch	23.2	2.7	-0.6	Left front bumper	15.6	1.8	-1.6	Left front bumper
Fuel flowmeter	--	--	--	--	11.3	3.3	-0.5	Right side of motor
Pressure cell, front	--	--	--	--	--	--	--	--
Pressure cell, rear	--	--	--	--	--	--	--	--
Ground position marker	1.3	0.5	2.6	Rear (right)	0.0	4.8	-0.3	Rear (right)
Distance	0.0	6.9	1.5	Rear (left)	-0.2	0.5	-1.8	Rear (left)

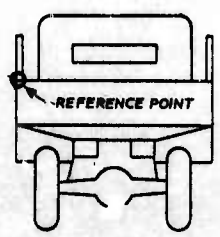
* Locations of reference points on vehicles are shown below (all dimensions in ft).



SIDE VIEW

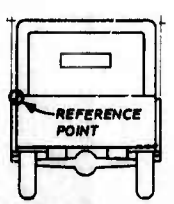


SIDE VIEW



REAR VIEW

M35A1 W/WINCH



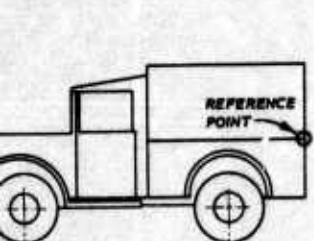
REAR VIEW

M37 W/WINCH

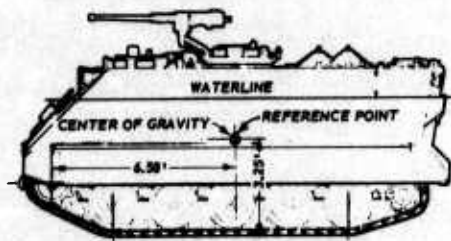
Table A4

Location of Transducers in Test Vehicles

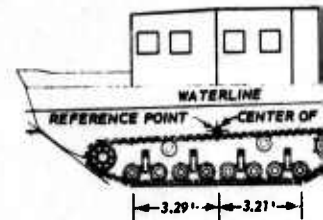
M37 3/4-ton Cargo Truck		M113 Armored Personnel Carrier			M29C Amphibious Cargo Carrier				
Vertical + Up - Down	Location	Displacement from Reference Point* in ft			Location	Displacement from Reference Point* in ft			Location
		Longi- tudinal + Fore - Aft	Lateral + Star- board - Port	Vertical + Up - Down		Longi- tudinal + Fore - Aft	Lateral + Star- board - Port	Vertical + Up - Down	
-1.9	Between transmission and transfer case	5.6	-0.2	-0.5	Between transmission and transfer case	-2.4	0.0	-0.5	Between transmission and transfer case
-2.4	Front of vehicle on a lateral axis	9.7	0.0	1.6	Front of vehicle on a lateral axis	--	--	--	
-1.9	Near universal joint, between transfer case and drive shaft	--	--	--	--	-3.3	0.0	-0.5	Near universal joint, between transfer case and drive shaft
-1.8	Under driver's seat	--	--	--	--	--	--	--	
-1.9	Left rear wall of cargo compartment	-0.8	3.5	1.5	Left side of inner cargo wall	-2.4	-1.5	0.5	Left side of inner cargo wall
-1.9	In speedometer receptacle at the rear of transfer case	7.0	-2.0	-1.7	In speedometer receptacle near connection between left sprocket and axle	-3.3	0.0	-0.5	In speedometer receptacle at the rear of transfer case
--	--	0.0	0.0	0.0	Attached underneath instrumentation table	0.0	0.0	0.0	Attached underneath instrumentation table
-1.6	Left front bumper	8.2	-2.6	-0.8	Left front, attached to hull	6.7	-1.6	0.0	Left front, attached to hull
-0.5	Right side of motor block	4.1	1.8	2.2	Left side of motor block	2.4	0.0	1.4	Left side of motor block
--	--	7.6	0.6	-2.0	Below engine maintenance door center	5.4	0.0	-0.5	Below engine maintenance door center
--	--	-6.9	0.6	-1.7	Below cargo door in the rear, off center to the left	-6.3	0.0	-0.5	Below cargo door in the rear, off center to the left
-0.3	Rear (right)	--	--	--	--	-6.8	1.9	0.0	Rear (right)
-1.8	Rear (left)	-6.5	3.5	0.6	Rear (left)	-7.3	1.7	1.6	Rear (left)



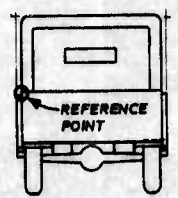
SIDE VIEW



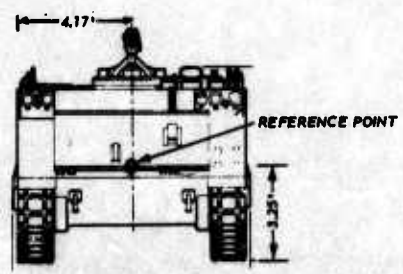
SIDE VIEW



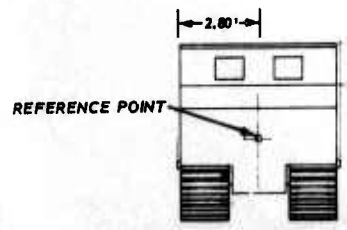
SIDE VIEW



REAR VIEW
M37 W/WINCH



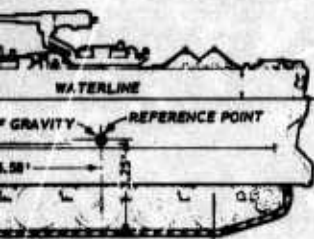
FRONT VIEW
M113



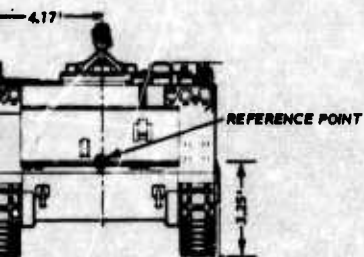
FRONT VIEW
M29C

icles

Armored Personnel Carrier		M29C Amphibious Cargo Carrier					M274 1/2-ton Light Weapons Carrier		
		Displacement from Reference Point* in ft							
		Longitudinal	Lateral	Vertical					
		+ Fore - Aft	+ Starboard - Port	+ Up - Down	Location		M151 1/4-ton Utility Truck	M274 1/2-ton Light Weapons Carrier	
Location									
	Between transmission and transfer case	-2.4	0.0	-0.5	Between transmission and differential	--	--	--	--
	Front of vehicle on a lateral axis	--	--	--	--	--	--	--	--
	--	-3.3	0.0	-0.5	Near universal joint, between drive shaft and transfer case	Between transmission and torque case	--	--	--
	--	--	--	--	--	Mounted on right side of driver's seat	--	--	--
	Left side of inner cargo wall	-2.4	-1.5	0.5	Left wall of cargo compartment	--	--	--	--
	In speedometer receptacle near connection between left sprocket and axle	-3.3	0.0	-0.5	In speedometer receptacle in the transfer case	--	--	--	--
	Attached underneath instrumentation table	0.0	0.0	0.0	Near forward wall of cargo compartment	--	--	--	--
	Left front, attached to hull	6.7	-1.6	0.0	Attached to hull (front left)	Left front bumper	--	--	--
	Left side of motor block	2.4	0.0	1.4	Left side of motor block	In line between fuel pump and carburetor	--	--	--
	Below engine maintenance door center	5.4	0.0	-0.5	Attached to hull below pintle (front)	--	--	--	--
	Below cargo door in the rear, off center to the left	-6.3	0.0	-0.5	Attached to hull below pintle (rear)	--	--	--	--
	--	-6.8	1.9	0.0	Rear (right)	Rear (right)	--	Rear (right)	--
	Rear (left)	-7.3	1.7	1.6	Rear (right)	Rear (left)	--	--	--

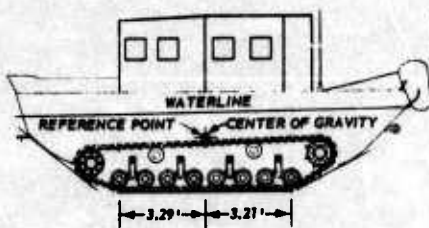


SIDE VIEW

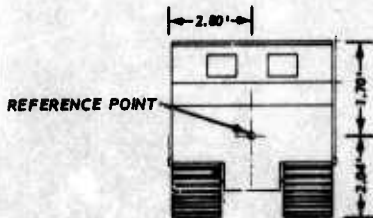


FRONT VIEW

M113

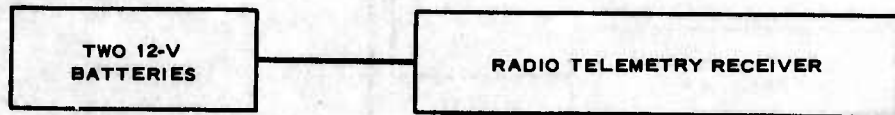
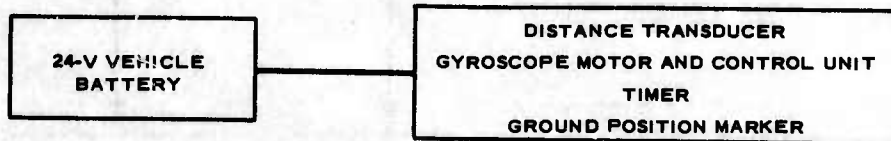
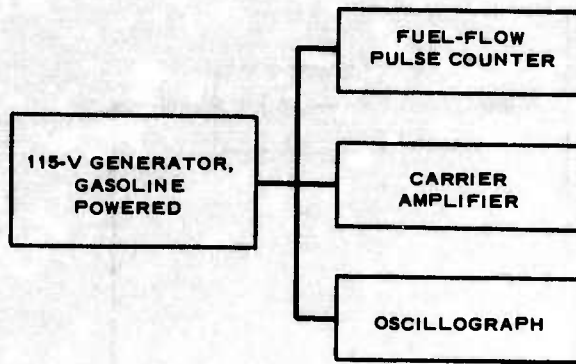


SIDE VIEW



FRONT VIEW

M29C



**POWER SUPPLY SOURCES
FOR TRANSDUCERS AND
RECORDING INSTRUMENTS**

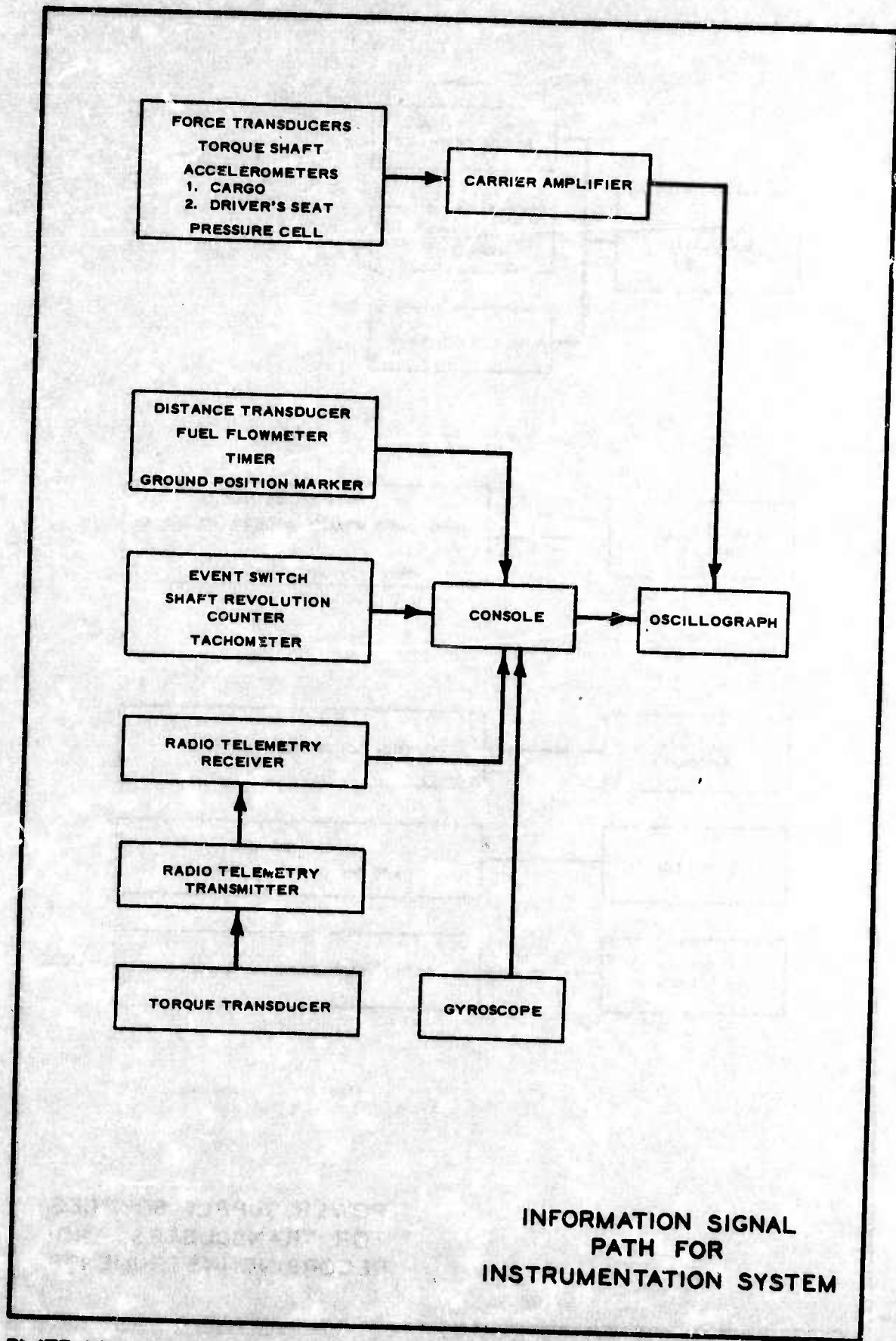
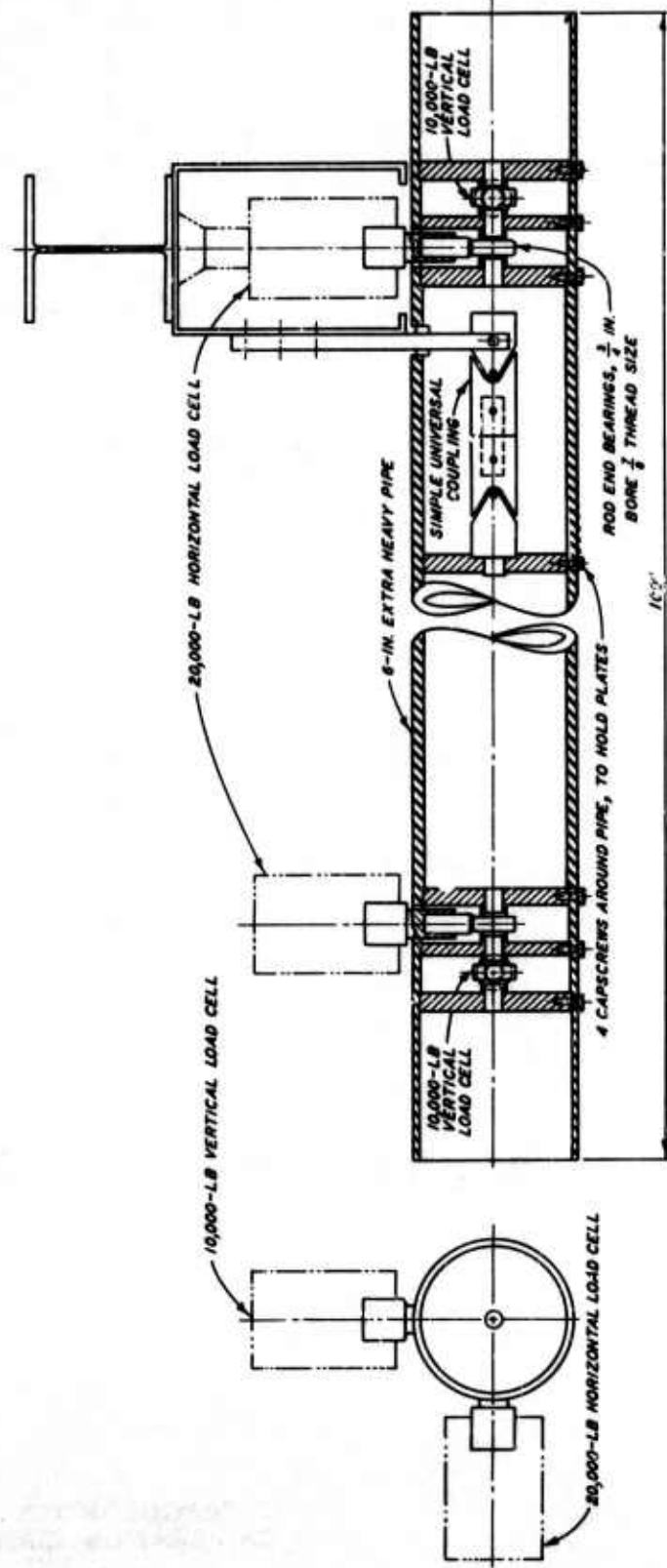


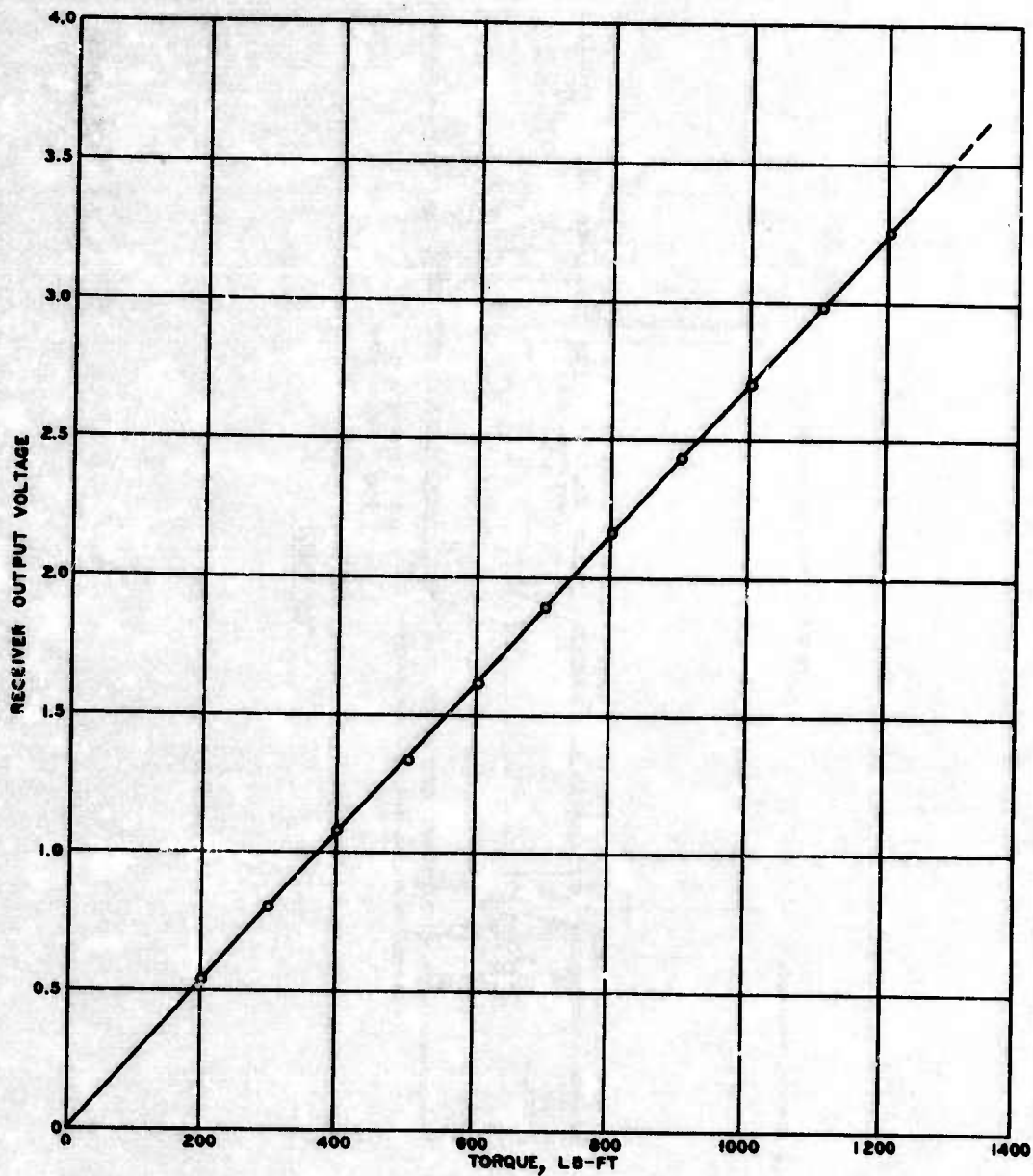
PLATE A2

M113 PUSHBAR



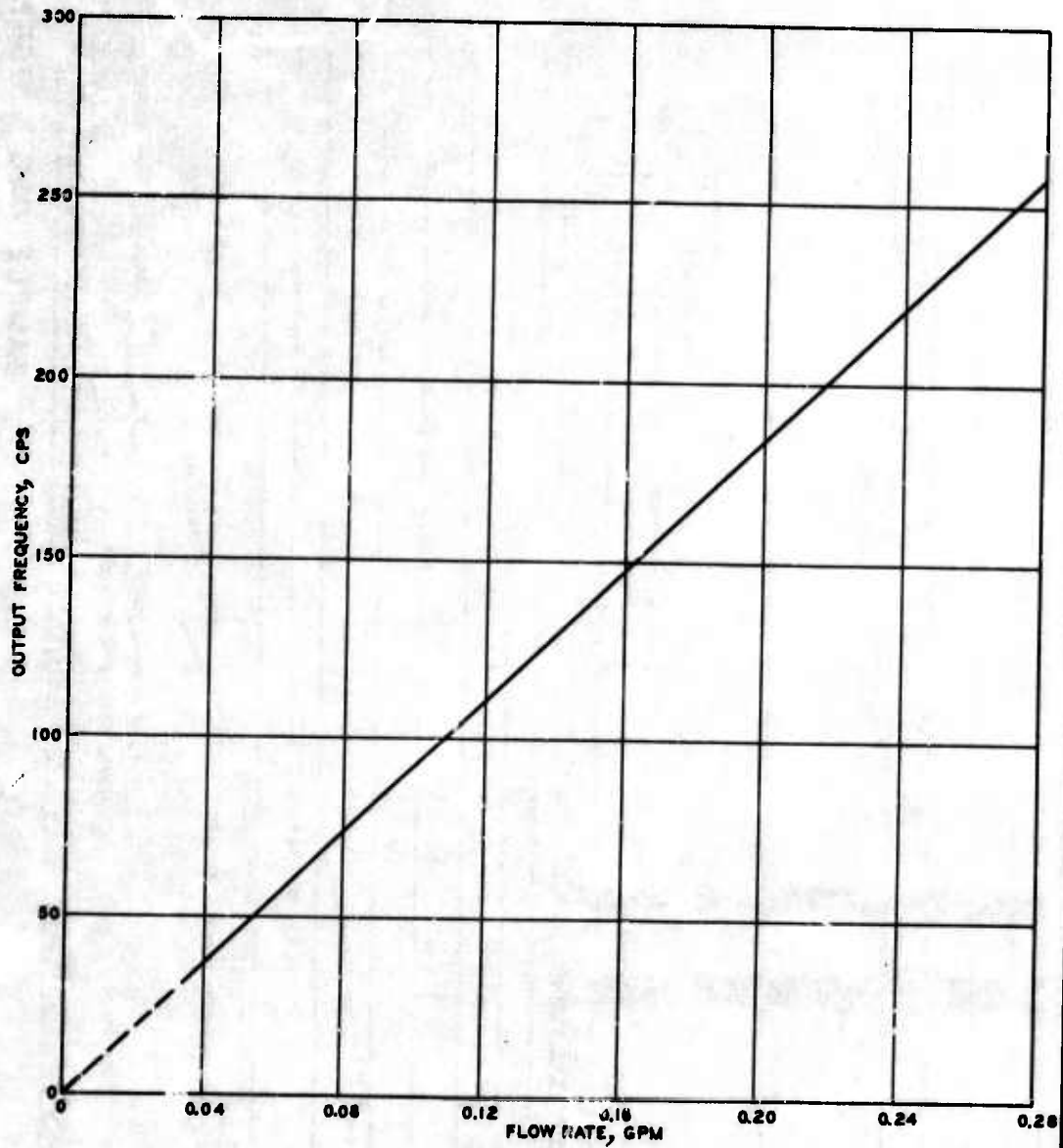
TOP VIEW

END VIEW



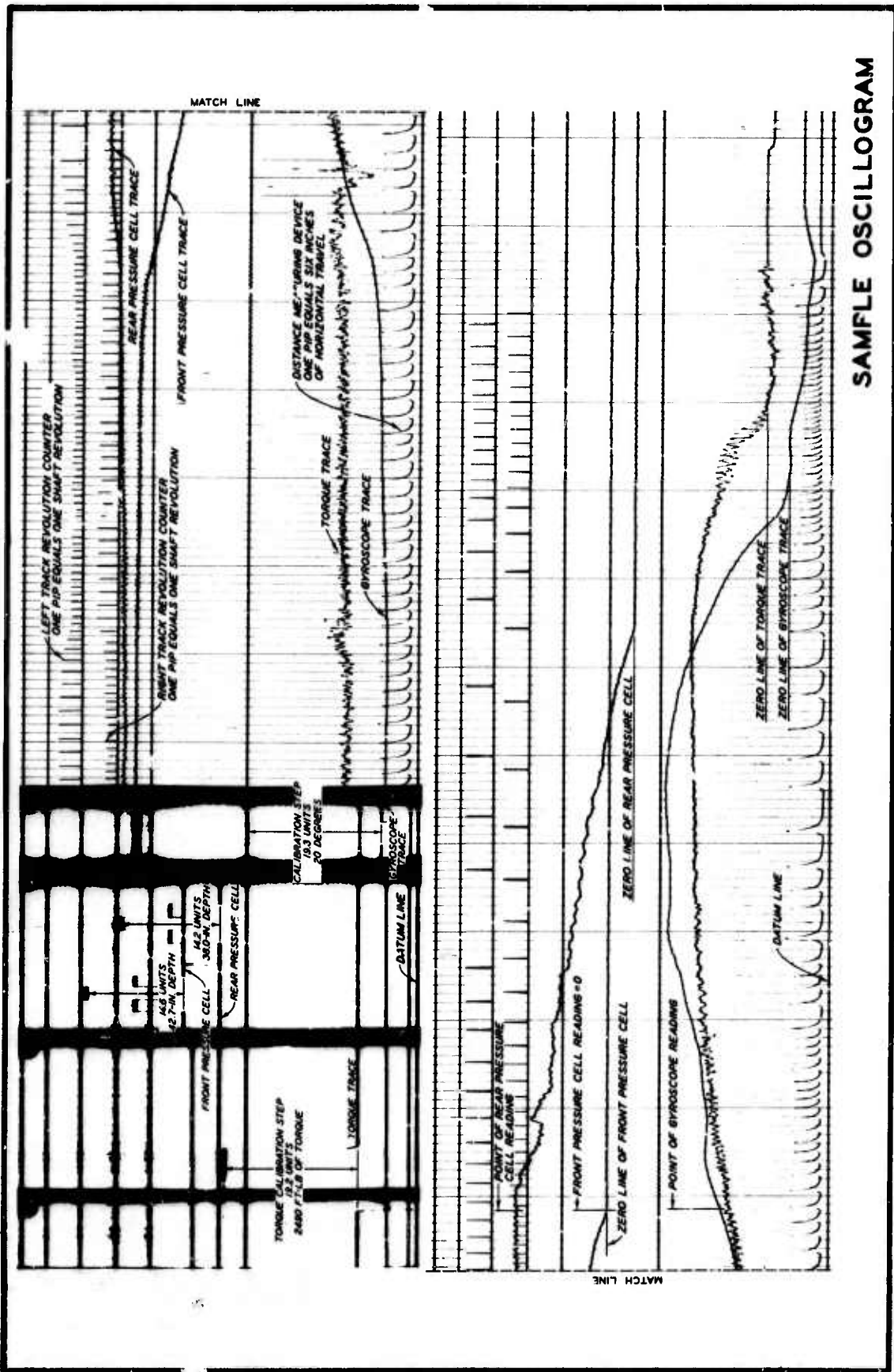
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8K-1% RANGE EXTENDER.

TORQUE METER
CALIBRATION CURVE
M37



FUEL-FLOW TRANSDUCER
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13. ABSTRACT

An instrumentation system was developed to measure and record the dynamic responses of a moving vehicle to discrete environmental factors. Measurements of force to override vegetation, drive-line torque, vehicle linear and wheel or track rotational displacement, fuel consumption, acceleration, pitch, and hydrostatic pressure were made to determine the effects imposed on the vehicle by soil and longitudinal, lateral, and vertical obstacles. The specific components of the system used for the various measurements are described and information concerning their positioning and operation is presented.

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